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SUMMARY-ANALYSIS OF HEARINGS MAY 27–29, AND JUNE 3–7, 1957

ON

THE NATURE OF RADIOACTIVE FALLOUT AND ITS EFFECTS ON MAN

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Printed for the use of the Joint Committee on Atomic Energy

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SUMMARY-ANALYSIS OF HEARINGS HELD MAY 27–29 AND JUNE 3–7, 1957, ON THE NATURE OF RADIOACTIVE FALLOUT AND ITS EFFECTS ON MAN

INTRODUCTION

During late May and early June the Joint Committee on Atomic Energy held 8 days of public hearings on the nature of radioactive fallout and its effects on man. It was the intent of these hearings to emphasize the scientific subject matter related to the fallout problem, and to leave broader policy issues to subsequent consideration. The hearings, including material introduced for the record and a comprehensive bibliography, will probably be the most extensive library of information on fallout yet to appear in one document.[1]

The hearings covered in detail the whole cycle of fallout from its inception in the detonation of nuclear weapons, through its scattering about in the atmosphere and descent to earth, and finally its uptake by and effect on human beings, animals, and vegetation. Testimony covered a breadth of scientific knowledge from physics to pathology, and from geology to genetics, as it relates to fallout. Some 50 experts from the major scientific areas involved were invited to present testimony before the committee and submit statements for the record. All sessions were open to the public.

The hearings accomplished several things. One thing was clarification of many important scientific points. Another was putting into better perspective much of the available scientific data on fallout. Most helpful, in this respect, were experimental round-table discussions among some of the expert witnesses. The discussions helped to point up the areas of agreement and to outline more clearly the areas of continuing disagreement.

The hearings served to bring out distinctions that must be made between fact and value judgment, and served to emphasize how difficult it is to give precise scientific definition to such words as "clean," "safe," and "hazardous," so that these words acquire exact meanings.

The scope of the subject matter covered in the hearings is so broad and often so technical and detailed that a comprehensive analysis and evaluation is likely to involve a broad segment of the scientific and lay community in this country, and others, for many months to come. The purpose of this summary analysis is more immediate: To put down in simple terms a statement of what the hearings were about and what the main issues were. It is to be recognized that

[1] The oral testimony will constitute a major portion of the printed hearings which will also include statements inserted for the record. Selected reprints of previously published technical reports and scientific journal papers are also included. The extensive bibliography, prepared by Mrs. Ruth A. Little, Legislative Reference Service, Library of Congress, is an important part of the record of the hearings.

preparing even a summary necessarily implies making value judgments as to what is to be summarized. The summary does not cover all of the wealth of information available in the print of the hearings.

The proper discussion of fallout, its nature, its effects, and its policy implications requires an understanding of certain facts and concepts that are not ordinarily before the layman's eyes in easily understandable terms. The fallout hearings were aimed at bringing out these ideas and facts so as to promote a better understanding by the Congress and the public of this complex question. Much of the information contained in the print of the hearings is technical. One of the purposes of this summary analysis is to simplify and clarify this information.

The Joint Committee on Atomic Energy went to great lengths, first, to insure that all of the major areas of background subject matter in the sciences would be covered and, second, that important points of difference on what the facts are, or what they mean, would be covered so as to bring out clearly what differences exist.

On May 22, 1957, a statement of the scope and approach of the forthcoming fallout hearings, and an outline of the subject matter were made available to all prospective witnesses and to the public. This material included specific questions to guide witnesses as to points the committee felt should be covered or emphasized to assure a full and balanced presentation. Witnesses were picked out primarily from the point of view of their scientific competence and familiarity with particular aspects of the fallout problem. Obviously, not all scientists in the country meeting that criterion could come before the committee to testify. The committee tried to pick out a representative sample and to achieve a balanced presentation reflecting varied points of view.

The committee intended that the basic responsibility for adequate coverage and presentation of the subject matter would fall on the expert witnesses themselves. One of the most satisfying aspects of the hearings to the Congress and to the country should be the unstinting efforts of the expert witnesses to see that the subject matter was fully covered and made understandable.

Before coming to his own conclusions concerning fallout effects, a person should understand the basic scientific facts now available. Information in the field of fallout effects, as for many other scientific fields of inquiry, is far from complete. However, these hearings should provide enough information to help a person to begin to understand the problems and issues involved, to see what the present scope of information is, and to see the areas yet to be explored.

SUMMARY OF KEY POINTS

Some general observations may be made on the results of the hearings:

1. *Origin of fallout.*—It was pointed out that all nuclear explosions can be expected to produce some radioactive materials. However, certain kinds of explosions produce very much less radioactivity than others. Although there is no such thing as an absolutely "clean" weapon (that is, there is no such thing as a nuclear weapon detonation completely free of accompanying radioactivity), the amount of the

radioactivity produced can be substantially altered in relation to the size of the explosion.

2. *Distribution of fallout.*—There was substantial, but far from complete, agreement on what happens to radioactive debris produced in man's environment, how much is there now, how and where it is distributed, and how much is in man himself. There was considerable evidence presented to indicate that in no part of the atmosphere is fallout uniformly distributed and that, therefore, the effects of fallout on the world's population could not necessarily be expected to be uniform.

3. *Biological effects of radiation.*—There was general agreement that any amount of radiation, no matter how small the dose, increases the rate of genetic mutation (change) in a population. There was, on the other hand, a difference of opinion as to whether a very small dose of radiation would produce, similarly, an increased incidence of such somatic (nongenetic) conditions as leukemia or bone cancer, or a decrease in life expectancy, in a population.

4. *Tolerance limits.*—There was general agreement that there is a limit to the amount of radioactivity and, hence, to the amount of fission products that man can tolerate in his environment. The extent to which existing and future generations will be affected by manmade radiation was shown to be intimately tied to certain decisions, moral as well as scientific, that must be made as to how much radiation can be tolerated by the peoples of the world.

5. *Effects of past tests.*—It was clearly shown that man's exposure to fallout radiation including strontium 90 is and will be in general small, *for the testing already done*, compared with his exposure to other, "normal background" sources of radiation (a fraction of 1 to 10 percent), and even compared with variations in "normal background" sources. But it was not agreed on how this information should be interpreted.

6. *Effects of future tests.*—There were differences of opinion on how to forecast the consequences of further testing. The differences hardest to reconcile appear to be those concerning the biological effects of radiation. Pending a resolution of differences, it would appear from the information presented that the consequences of further testing over the next several generations at the level of testing of the past 5 years [2] could constitute a hazard to the world's population. It is very difficult, if not impossible, to forecast with any real precision the number of people that would be affected.

7. *Effects of nuclear war.*—The catastrophic nature of the radiation effects from a multiweapon (atomic and hydrogen bombs) attack on the United States were clearly portrayed. This, of course, could be applied to any nation.

These points will be discussed in more detail.

MAJOR UNRESOLVED QUESTIONS

A number of unresolved questions emerged from the hearings. Among the chief of these are—

1. How "clean" can nuclear weapons actually be made? The solution to this question lies in the future of weapons development.

[2] It has been estimated that about 50 megatons equivalent yield of fission products have been put into the atmosphere so far by all countries.

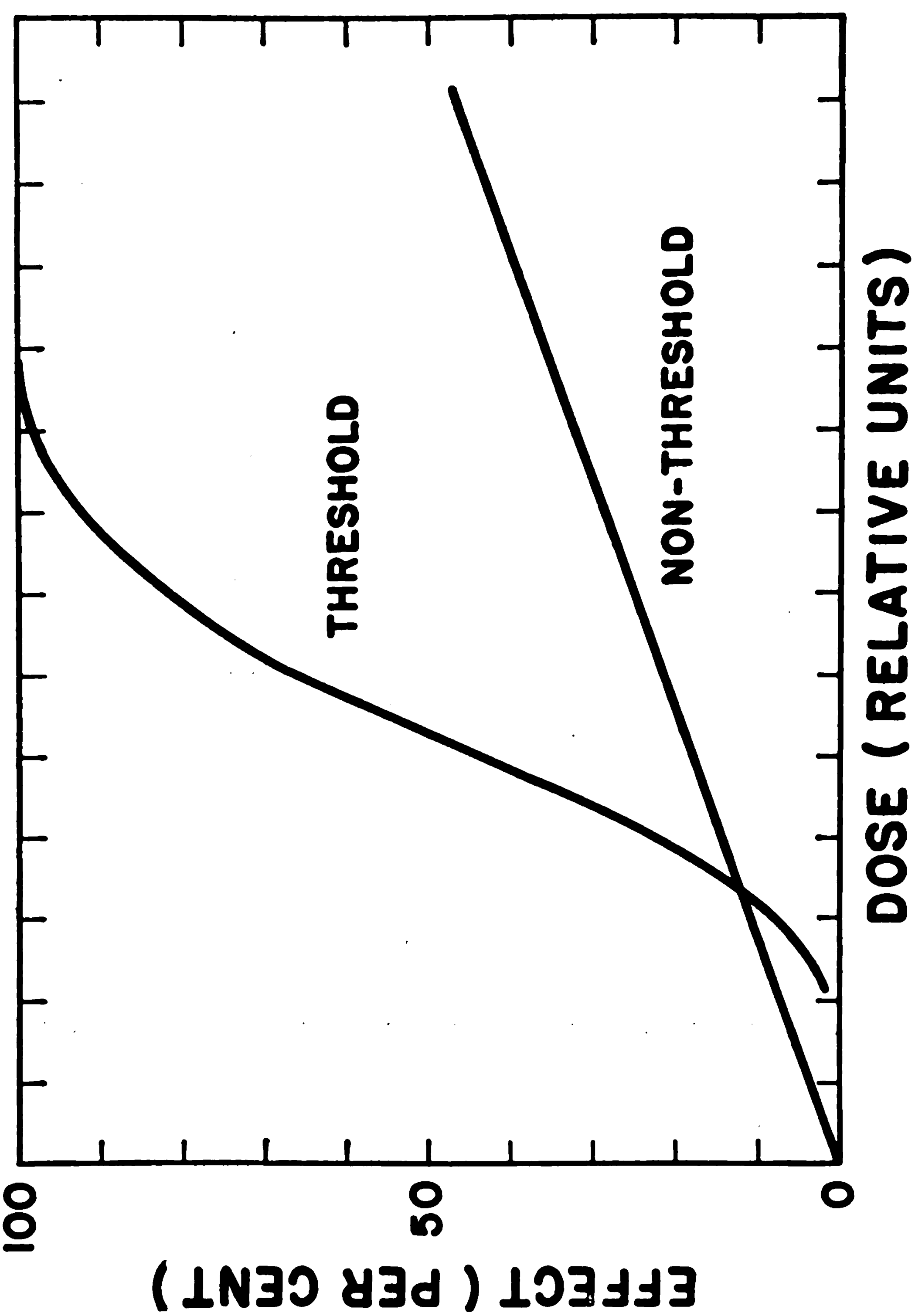

FIGURE 3.—A pictorial representation of the difference between a threshold and a nonthreshold situation. Dose increases to the right. Note that the non-threshold line is a straight line; it needn't be. (See p. 15.) [Figure reprinted from testimony of Drs. Langham and Anderson, Los Alamos Scientific Laboratory.]

THE NATURE OF RADIOACTIVE FALL-OUT AND ITS EFFECTS ON MAN

HEARINGS

BEFORE THE

SPECIAL SUBCOMMITTEE ON RADIATION

OF THE

JOINT COMMITTEE ON ATOMIC ENERGY

CONGRESS OF THE UNITED STATES

EIGHTY-FIFTH CONGRESS

FIRST SESSION

ON

THE NATURE OF RADIOACTIVE FALLOUT AND ITS EFFECTS ON MAN

MAY 27, 28, 29, AND JUNE 3, 1957

PART 1

Printed for the use of the Joint Committee on Atomic Energy

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2. H. A. Bethe, Reactor Safety and Oscillator Tests, APDA-117, Avail AEC, October 1956.
3. Letter: Harold S. Vance to Hon. Carl T. Durham, March 22, 1957; and enclosure, Theoretical Possibilities and Consequences of Major Accidents in Large Nuclear Powerplants, United States AEC, March 1957 (the Brookhaven Report).
4. C. R. McCullough, M. M. Mills, E. Teller; The Safety of Nuclear Reactors, Chem. Eng. Progress, October 1955, pp' 446–450.
5. Reference 1, pp. 132–150.
6. R. F. Post, Controlled Fusion Research, Rev. Med. Phys. 28, 338 (1956).

Representative HOLIFIELD. The committee will stand adjourned until 2 o'clock when we will have Dr. Graves and the people from the Department of Defense before us.

(Whereupon, at 12:30 p. m., the committee recessed, to reconvene at 2 p. m., of the same day.)

AFTERNOON SESSION

Representative HOLIFIELD. The committee will be in order. It is our intention this afternoon to have testimony on the production of radiation and radioactivity by the detonating of nuclear weapons.

Our first witness on this subject is Dr. Alvin C. Graves, of the Los Alamos Laboratory. Dr. Graves, this committee is pleased to have you before us again. You have been before us many times over the past 10 or 11 years, and I know of no one that is better qualified to give us testimony on this subject than you, because you have had charge in a great many instances of these weapons tests.

So at this time, sir, the committee would be glad to hear your testimony.

STATEMENT OF DR. ALVIN C. GRAVES, LOS ALAMOS SCIENTIFIC LABORATORY[a]

Dr. GRAVES. Mr. Chairman, we are teachers at heart and are used to talking at the blackboard. So if you will pardon me, I will feel much more at home if I can talk at the board.

I would also like very much to express my regret to you that I was unable to prepare a written statement for you in time to be submitted for the record beforehand. On the other hand, I do have a written record here now, and if I may leave this with you, you can make such disposition of it as seems appropriate to you.

Representative HOLIFIELD. Thank you.

Dr. GRAVES. In this, the fifth topic of the hearings before your committee, you have asked me to cover the production of radiation and radioactive materials by nuclear-weapon detonations.

Although Dr. Mills in his discussion this morning went into the fission and fusion processes to some extent, I would like to go over some of the material that he covered, because the production of radia-

[a] Physics. Date and place of birth: November 4, 1909; Washington, D. C. Education: Bachelor of science, Virginia, 1931; doctor of philosophy (physics), Chicago, 1939. Work history: Instructor, physics, Texas, 1939–41; assistant professor, 1942–42; associate professor, 1942–; member staff, metallurgical laboratory, Chicago, 1942–43; Los Alamos Scientific Laboratory, California, 1943–45; group leader, 1945–46; associate division leader, 1946–48; division leader, 1948–; Deputy Science Director, Pacific Proving Ground activities, 1947–48; science director, 1950–; test director, Nevada Proving Ground activities, 1951–; with Office, Scientific Research and Development, 1944. Physical Soc. Mass spectroscopy; cosmic rays; neutron physics; nuclear reactions. (From American Men of Science.)

tion and radioactive material is in this set of processes and, unless we cover them carefully, we will not be able to make the production of radiation understandable.

Moreover, in view of the desire to have this hearing not only for our own purposes but for purposes of informing the public, I hope you will bear with me if I speak to some extent on material which is well known to you.

Representative HOLIFIELD. Would you like to have the prepared testimony put in as you have prepared it, Doctor Graves?

Dr. GRAVES. If you would.

Representative HOLIFIELD. It will be accepted on that basis.

(The statement referred to follows:)

THE PRODUCTION OF RADIATION AND RADIOACTIVITY BY DETONATING NUCLEAR WEAPONS

(By Alvin C. Graves)

In this, the fifth section of the hearings before your committee, you have asked me to cover the production of radiation and radioactive materials by nuclear-weapons detonations. Although earlier witnesses have presented you with general background material on atomic radiation and its effect, I feel it appropriate to risk some repetition in my discussion since the origin of radiation and radioactive materials in detonations is in the fission process and in reactions with neutrons produced in the detonation. In view of your desire to use this investigation to inform the public on the subject of fallout from nuclear-weapons tests, I should like to request your indulgence if I speak to some extent on material which is already well known to you.

1. Description of nuclear-weapon detonation

Nuclear weapons differ from normal high-explosive bombs in three important respects. In the first place, their energy may be made orders of magnitude greater; second, their detonation is accompanied by intense thermal and nuclear radiation; and, third, there remains when the detonation is completed extremely large amounts of radioactivity. In describing the detonation of an atomic weapon completely, one should discuss in great detail blast effects, which differ in some important ways from blast effects of normal explosions, thermal radiation, and light which, as mentioned above, are novel features of nuclear detonations, initial nuclear radiations consisting of gamma, neutron, alpha, and beta radiations and, finally, delayed radiations. However, for purposes of this hearing, I propose to place my major emphasis on the last two of the above topics.

The release of energy in nuclear detonations deposits a very large amount of energy in a very small region of space in an extremely short time. For example, the complete fission of 1 pound of uranium (a little over a cubic inch) would produce an amount of energy equivalent to 9,000 tons of TNT, and the fusion of a pound of deuterium would produce energy equivalent to 26,000 tons of high explosive. Hence, the initial effect is a rise of temperature of bomb materials to a very high temperature of many million degrees as contrasted with perhaps 5,000 degrees in the case of ordinary high explosives. This extremely high temperature, not very different from that at the center of the sun, is accompanied by tremendous pressures such that, at a very few microseconds, pressures of the order of millions of pounds per square inch exist, and an expansion of vaporized bomb materials begins to take place. At 0.7 millisecond, the fireball for a 1-megaton detonation will have a radius of 220 feet, and at about 10 seconds will have reached its maximum diameter of about 7,000 feet. This growth in size is accompanied by a decrease in temperature and pressure, formation of a shock wave which produces the familiar blast effects and, at the same time, the fireball begins to rise and to engulf large quantities of surrounding materials, air, dirt, or water, depending on the particular situation in which the bomb was detonated. While the ball of fire is still luminous, fission products, fissionable material, bomb casing, and other materials will be present in the form of vapor, whereas, as the fireball increases in size and cools, these vapors will condense and be absorbed in or on other particles such that the cloud becomes a mixture of gaseous and solid radioactive particles. The cloud from a weapon in the megaton range would rise initially at a rate like 250 miles per

hour and, after a minute, would have risen perhaps 4 miles or more. It is the extremely rapid rise of fireball which makes meaningful a distinction between immediate or prompt radiation and delayed or residual radiation. The amount of radiation which can reach a point from distances like 4 miles is small and, hence, establishing an arbitrary division by defining all radiation delivered in the first minute as prompt radiation and all after 1 minute as residual radiation tends to correspond to a distinction between that radiation which is delivered from the fireball and that which is delivered from fallout, or from deposited or induced radioactive materials. Because of its connection with the problem of radiation, the following table is given as an illustration of the rise of a cloud from a 1-megaton detonation.

Rate of rise of cloud from 1-megaton detonation

Height (miles)	Time (minutes)	Rate of rise (miles per hour)
2	0.3	300
4	0.75	200
6	1.4	140
10	3.8	90
14	6.3	35

With different detonation yields and atmospheric conditions, different times and rates of rise would, of course, be observed.

2a. The fission process

For our purposes, an atom may be represented as composed of a massive central nucleus and a number of relatively light electrons rotating about it. The revolving electrons are important in ordinary chemical reactions, but in nuclear reactions it is the nucleus which is of importance. In most reactions in which a neutron is involved, the resulting nucleus will have nearly the same mass as the original nucleus and, hence, the number of possible product nuclei is very small. In the fission process, where the fissioning nucleus splits into two unequal pieces, both of which are very different in mass from that of the original atom, the number of possible product nuclei is very large indeed. It seems, for example, that U-235 may be split in something like 40 different ways, and that over 200 different nuclides, counting primary fission fragments and decay products, may be formed. Since these products are highly radioactive, for reasons that I will discuss, the resulting radioactivity is that of a mixture of many radioactive nuclei with different periods and different modes of disintegration.

The simplest atomic nucleus is that of hydrogen, which has an atomic mass of 1, contains 1 unit of electrical charge, and is known as the proton. All other atomic nuclei contain a number of protons and neutrons. The neutron also has an atomic mass of 1, but has no electrical charge. Hence, a neutron can be converted to a proton by loss of an electron. In nature there appears to be a strong tendency for the number of neutrons and protons in nuclei to be equal. For example, the helium nucleus contains 2 neutrons and 2 protons. The nucleus of 1 species of lithium contains 3 neutrons and 3 protons; boron, 5 neutrons and 5 protons; carbon, 6 and 6; nitrogen, 7 and 7; oxygen, 8 and 8; and so forth. Hence, uranium, with its 92 protons and 143 neutrons, is very neutron rich, and fragments resulting from fission are unstable such that, to become stable, they must either lose neutrons or convert neutrons into protons. Both processes occur. A number like 2, 3, or 4 neutrons is emitted, essentially instantaneously. And then, at various times from a small fraction of a second to many years, a nuclear neutron is converted into a nuclear proton by the emission of an electron. A fraction of 1 percent of emitted neutrons are delayed. That is, although about 99¼ percent of neutrons will be emitted within about 10 to 12 seconds of fission, ¾ percent will be emitted at times as long as several minutes. Periods for delayed neutrons vary from a fraction of a second to almost a minute.

Reference to the fission yield curve of U-235 indicates that production of masses 95 and 139 should be a common mode of fission of that element. A reasonable distribution of uranium protons suggests that these fragments might be Sr-95 and Xe-139. These fragments would both be unstable and would decay by the following processes:

$$Sr^{95} \rightarrow Y^{95} \rightarrow Zr^{95} \rightarrow Cb^{95} \rightarrow Mo^{95} + 4e^{-} + \text{gamma rays}$$
$$Xe^{139} \rightarrow Cs^{139} \rightarrow Ba^{139} \rightarrow La^{139} + 3e^{-} + \text{gamma rays}$$

Hence, in that particular mode of fission, 4 radioactive decays would occur in the light element and 3 in the heavy, with the emission of 7 electrons with 7 different decay periods, and with the production of many gamma rays of many energies. In fission with slow neutrons, production of stable fission fragments appears to be rare, although short chains of 1 or 2 decay stages appear. Two of the longest known are $Kr^{97} \rightarrow Mo^{97}$ among lighter fission products, and $Xe^{143} \rightarrow Nd^{143}$ among heavier. Each chain involves 6 stages of decay. The average is about 3 stages, or slightly more. During most such processes, gamma rays of various energies are emitted. These phenomena, involving the conversion of one element into another with emission of gamma rays and electrons, are the cause of much of the radioactivity observed in fallout. Induced activity will be discussed in a later section.

2b. Fusion process

The fusion process is quite different from the above and, hence, has a different importance in radiation and fallout considerations. Among light elements, binding energy per nuclear particle tends to decrease with increasing mass as contrasted with an increase with increasing mass in heavy elements. Hence, among light elements energy is released when light elements are joined together to make heavy elements. Such reactions, because of this process of joining atoms together, are called fusion reactions and, because they can be initiated and sustained by high temperatures, are also known as thermonuclear reactions. The number of modes is always extremely limited, at least for low energies and low mass numbers, as contrasted with the large number of modes in fission. Two atoms of deuterium, for example, can fuse in two ways; one involves production of hydrogen of mass 3 or tritium and a proton; the second involves production of helium of mass 3 and a neutron. In this case, only tritium is radioactive. Moreover, tritium itself has a very high probability of fusing with deuterium so that, under many conditions, tritium will combine with deuterium to produce helium of mass 4 and a neutron. In deuterium fusion, the following reactions might occur:

$${}_1H^2 + {}_1H^2 \rightarrow {}_2He^3 + {}_0n^1 + 3.2 \text{ Mev}$$
$${}_1H^2 + {}_1H^2 \rightarrow {}_1H^3 + {}_1H^1 + 4 \text{ Mev}$$
$${}_1H^2 + {}_1H^3 \rightarrow {}_2He^4 + {}_0n^1 + 17 \text{ Mev}$$
$${}_2He^3 + {}_2He^3 \rightarrow {}_2He^4 + 2{}_0n^1 + 11 \text{ Mev}$$

Hence, the net direct result of fusing deuterium nuclei is production of protons, alpha particles, and many neutrons, but essentially no radioactive particles.

2c. Induced activities

A secondary source of radioactive materials results from neutrons produced in both fission and fusion processes. It was mentioned above that, depending on the particular mode of fission, two or more neutrons may be emitted and that deuterium fusion is accompanied by production of many neutrons. In any detonation of a nuclear weapon, some of these neutrons will escape and react with nitrogen atoms in air to form carbon 14 which is radioactive. In case detonations occur under conditions such that dirt is exposed to neutrons, many other neutron reactions can occur. Normally, radioactive materials induced by such processes have relatively short lives and will not be of major importance. Carbon 14, however, has a long life of over 5,000 years. Since it emits no gamma rays and only relatively weak beta rays, and since the amount formed will not be large compared to that that is present in nature, it will not be a significant activity. Oxygen absorbs fast neutrons to some extent, but the isotope of nitrogen formed has a half-life of only 7 seconds and, after a few minutes, will have completely decayed.

An important contribution to residual activity will be due to 14.8-hour sodium 24 formed by neutron capture by sodium. It emits beta particles and two relatively high energy gammas of 1.4 and 2.8 Mev. 2.6-hour Mn-56 emits beta particles and several high energy gammas. With some soils this element might cause an appreciable activity for a few hours, but within a day its activity would have been reduced to less than a percent of its initial amount. Si-31, with a half-life of 2.6 hours, is formed in appreciable quantities but is chiefly a beta emitter. Al-28 has a half-life of only a few minutes and, hence, will have disappeared in the first hour. The chlorine present in salt produces 37-minute Cl-38 which emits betas and high energy gammas.

Other materials such as zinc, copper, iron, glass, and salt in foodstuffs might, under some conditions, become active enough to be significant. Normally, how-

ever, induced activities will have a short half-life and make a significant contribution for only a relatively short time or will have little energy to emit.

2d. Initial radiation

As stated earlier, initial nuclear radiation is defined as that radiation which is delivered during the first minute after a detonation. Although initial neutrons and gamma rays constitute only about 3 percent of bomb energy as compared with 33 percent appearing as thermal radiation, a considerable proportion of bomb casualties can be caused by initial nuclear radiations. Fifty percent of people shielded by as much as about 2 feet of concrete would be killed by initial gammas and neutrons 1 mile from a 1-megaton bomb. A much lighter shield would give complete protection from thermal radiation.

Initial radiation consists of almost all neutrons, a part of gamma radiation, some beta and alpha rays. Alpha particles come from two sources. They are emitted from fissionable materials, plutonium and various isotopes of uranium, or from thermonuclear or other reactions in which alpha particle emission takes place. Beta particles come from fission fragment decay, as well as from such processes as photoelectric and Compton effects. Alpha particles, besides being relatively rare, have a short range like an inch or so in air and, hence, are not important in initial radiation. Beta particles have somewhat greater range but still cannot reach the ground from an air-burst. Both neutrons and gammas penetrate air to considerable distances and both are highly injurious to living organisms. Hence, they constitute by far the most important part of initial radiation. To a great extent, neutrons are slowed down and captured in bomb materials themselves, but enough fast neutrons escape to constitute an appreciable hazard at considerable distances. Only about a percent of gamma rays produced directly in fission escape from the immediate region. However, this contribution and that of gamma rays produced in other processes, as discussed below, produce sufficient intensity at considerable distances to constitute a real hazard. Gamma rays present in initial radiation come from a number of different sources. They originate not only in fission but also in various other neutron reactions. First, neutrons may be captured with formation of a highly excited compound nucleus which may lose its excitation by emission of gamma rays. For example, when neutrons are captured by nitrogen to form C–14, two high energy gamma rays are emitted. These can be an important component of initial radiation. Second, neutrons may also react with nuclei with the emission of protons or alpha particles, and gamma rays are frequently emitted in such processes. And, finally, neutrons may be scattered inelastically by nuclei with the emission of gamma rays. That is, a fast neutron in a collision with a nucleus may transmit some of its energy to that nucleus leaving it in an excited state. The excited nucleus may then revert to its normal state by emission of a gamma ray.

Fission fragments themselves decay with periods from a millionth of a second or less to many years, and many of these decays during the first minute are accompanied by emission of gamma rays known as delayed gammas. Although instantaneous and delayed gammas contributing to initial gamma radiation are produced in about equal amounts, instantaneous gammas are absorbed so strongly that they constitute only about 1 percent of external dose.

Gamma rays lose energy or are absorbed in going through matter, by excitation and ionization. It is believed that the chemical decomposition of molecules caused by this effect is the major cause of injury to animals and plants. Therefore, quantity of gamma radiation or gamma ray dose is defined in terms of ionization produced. The dose-distance relationships for gamma rays and neutrons are exceedingly complicated because of the large number of effects involved, but rough analytical expression can be obtained. Since surface area of a sphere increases with square of radius, intensity—that is, gamma rays (or neutrons) per square centimeter—will decrease with square of distance. In addition, since gamma rays and neutrons are strongly absorbed, degraded in energy, and scattered in air and other materials, there will be an exponential decrease depending on the absorption properties of air and these materials. Due to a balance between various effects, gamma ray dose at a given distance is roughly proportional to the yield up to about 80 or so kilotons. But, above that, the dose increases sharply with yield such that at 100 kilotons the dose will be 50 percent higher than indicated by a direct proportion, and at a megaton will be high by about a factor of five. This increase is due to decreased air density because of long negative pressure phase associated with large yields, and is partly counterbalanced by increased dose at lower yields caused by slower cloud rise with con-

sequent increase in contribution from fission product gamma rays. The net effect is very complicated, but roughly gamma ray dose decreases by a factor of 10 every 780 yards, in addition to inversely as the square of distance, and neutron dose decreases by a factor of 10 every 560 yards. Appropriate consideration of all the above factors indicates that dose-distance relationship for gamma rays can be approximated roughly by the following formula:

$$N = \frac{8.4 \times 10^{8} W}{D^{2}} e^{-D/343} \text{ rems}$$

where W′ is yield in kilotons increased at yields of 100 kilotons or above, as indicated previously, and D is distance in yards.

Neutron dose-distance relationship may be expressed to a very poor degree of approximation by the following formula:

$$I = 1.4 \times 10^{8} \frac{W}{D^{2}} e^{-D/238} \text{ roentgens}$$

This ignores variations because of variation in neutron capture in bomb materials for different designs, as well as differences because of high energy neutrons from fusion reactions, and so on.

2e. Residual radiation

About 0.11 pound of fission products are produced for each kiloton of fission energy yield and its radioactivity at one minute would be comparable with that of many pounds of radium. A megaton of fission energy would, therefore, result in activity at one minute comparable with that of very many tons of radium. During the first 24 hours there would be a decrease by a factor of more than 6,000, but it has been estimated that this activity, if uniformly spread over 10,000 square miles, would cause a radiation intensity after 24 hours of 2.7 roentgens per hour at a distance of 3 feet above the ground. Unprotected personnel in that area would receive more than 300 R after the first day. During the first day they would receive many times that amount. Of course, activity would not be spread uniformly over such an area. Actual fallout situations will be covered by later speakers.

An indication of the speed with which fission product activity decreases can be obtained by the rough rule that for every sevenfold increase in time there will be a tenfold decrease in activity. For example, after 7 hours the activity would be one-tenth of its value at 1 hour; after 49 hours, or about 2 days, it would be 1 percent of its value at 1 hour; and after about 2 weeks, it would be one-tenth of a percent of its value at 1 hour.

There is given below the estimated total gamma activity of fission products from a 20-kiloton atomic bomb, expressed in megacuries, at various times after the detonation.

Total gamma activity of fission products in megacuries

Time:	*Activity*	Time—Continued	*Activity*
1 minute	820,000	1 month	2.3
1 hour	6,000	1 year	.11
1 day	133	10 years	.008
1 week	13	100 years	.0006

3. Partition of energy from detonations

The partition of energy from a nuclear explosion as betwen blast and shock, thermal radiation, and nuclear radiation varies appreciably with device design and with condition of firing. As a general approximation, nevertheless, I shall give the division which could be expected from detonation of a device of 1-megaton yield, fired within the earth's atmosphere, but at such an altitude that comparatively little extraneous material would be available to be made radioactive by escaping neutrons (as for example, if fired at an altitude of a few thousand feet above the earth). To some extent such a partition is meaningless since eventually all forms of energy will be converted to heat. However, initially energy is partitioned about as follows. About half the energy would be released as blast or shock, one-third would occur as thermal radiation (heat or light), and some 15 percent would be in the form of nuclear radiation. Of this 15 percent roughly one-third would be initial radiation occurring within

1 minute after firing, while two-thirds would be residual radiation. Some residual radioactivity can be deteced for many years after detonation.

The blast or shock energy would have effects quite similar to those experienced in case of ordinary high explosive detonations. These would consist of an initial shock front (the first arrival of highly compressed air), a later region of high and low pressures behind the shock front, and a violent wind flow. The latter would initially be directed in an outward direction, but later in a reverse direction. In the case of a typical air burst, the distance at which a given overpressure occurs varies generally as the cube root of yield. The term "generally" is used since effects such as reflection and refraction of shock waves, dust loading, and the like, may increase or decrease pressures and materially change blast effects at a given point. As an indication of the order of magnitude of the effect one might expect from blast phenomena, the burst of a 20-kiloton weapon at an altitude of several hundred feet would destroy beyond economical repair multistory reinforced concrete buildings at distances up to a half mile. A 1-megaton burst fired under comparable conditions would cause similar damage at distances up to 2 miles.

The one-third of weapon energy emerging in the form of thermal radiation is contained initially in a relatively small voume of air and incandescent gases resulting from vaporization of device components. This intensely hot spherical mass termed "fireball' is visible until thermal energy has been dissipated and temperature reduced to such an extent that visible light is no longer emitted. The initial fireball temperature is of the order of several million degrees and thermal radiation is made up of rays in the ultraviolet, visible, and infrared. As the fireball cools there is a shift to long wavelengths, but phenomena are complicated by absorption in outer portions of the fireball and in shocked air, by change from emission to absorption spectra, and by changes in position and chemical composition of materials involved. The extent of injury or damage to a person or material from thermal radiation is a function of total energy and of time duration of pulse received. From a given weapon, or from weapons of comparable yield, quantity of thermal radiation energy received per unit area is primarily a function of distance from burst. The amount decreases inversely as distance squared and exponentially because of attenuation in the atmosphere. The period over which thermal energy is given off from an explosion increases with yield—that from a kiloton device being limited to a few tenths of a second but, for a megaton device, the period may extend to several seconds. A 20-kiloton burst could be expected to ignite combustible materials at ranges up to 2 miles, while a 1-megaton burst could have similar effect up to 10 miles. The 20-kiloton burst could cause first degree burns to exposed skin surfaces at ranges of 3 miles, while a megaton burst could cause similar burns at 14 miles.

The partition of energy between various nuclear radiations as observed at a distance depends materially on device design and cannot be discussed in detail in unclassified language. It should be sufficient to point out that neutrons are efficiently converted to gamma rays in heavy materials, gamma rays are absorbed and converted to thermal energy in heavy materials, and neutron energy spectrum depends materially on whether, or on the way in which, fusion reactions are employed, and on the kind and amount of heavy materials used.

4. Types of burst and effect on fallout

For descriptive purposes, three types of burst can be distinguished. These are air, surface, and subsurface bursts. A high air burst is one in which the hot fireball does not touch the earth and, for a megaton device, is about 3,000 feet high or more.

Initial nuclear radiations are absorbed and scattered less in low density air associated with air bursts. Hence, there is less energy degradation and mean free paths are longer. Additionally, less dirt is stirred up to further absorb and scatter radiation. The result is that dose at a given distance is greater.

In the event of high air bursts, fission products are widely dispersed and very little is deposited on the ground under or near the point of detonation. This is the safest type of burst from the point of view of nearby regions as far as fallout is concerned. However, this puts the maximum amount of activity into the atmosphere and is the worst type as far as worldwide fallout is concerned. As height of burst is decreased toward the earth's surface, more and more dirt is mixed with the cloud and more of the activity is absorbed on larger, more massive particles and, hence, falls out locally.

In the case of subsurface bursts, much initial radiation is absorbed within a short distance of the explosion and dissipated in heating ground or water or, in the case of neutrons, in producing induced activities. As depth of detonation increases, less activity appears in the atmosphere and more is deposited locally. Under such conditions, the maximum local fallout and minimum worldwide fallout occurs. At sufficient depths, the detonation would be entirely contained and no fallout problem would exist. Ground water contamination concentration would be a maximum for the latter case and a minimum for high air bursts. Subsurface bursts under water have extreme contaminating effects, and effects on marine life and contamination of seafood can be serious.

5. Limitation on data

Although initially residual radiation decreases approximately as t-1.2, departures from the law becomes appreciable after the first half year or so. Better data on dose and gamma ray energy as a function of time is desirable.

In estimating dose to people one needs knowledge of shielding of typical structures and data for calculating probable dose reduction to individuals engaged in typical activities.

After long time intervals, when most activities will have decayed to such an extent as to be negligible, the activity remaining will largely consist of Cs–137 and Sr–90. More data is needed on uptake of these materials in plants, their conversion to food, and effect on biological systems.

In order adequately to discuss residual radiation for typical situations, much more data is needed as to particle size versus height in the cloud as a function of type of burst, and activity per particle as a function of particle size and position of particle.

Although much effort has been expended on determination of patterns of deposition of residual radioactivity, existing data leaves much to be desired, especially for large yields.

6. Recommendations

It is recommended that:

1. Additional effort be allocated to obtain data as indicated above.

2. Since the actions of individuals within seconds after a detonation could make a difference of thousands of fatalities and could decrease the seriousness of many casualties, it is recommended that increased effort be expended in informing the American people of the effects of weapons and in establishing personal civil defense.

Dr. Graves. I would like to give you a general description of a nuclear-weapon detonation.

Nuclear weapons differ from normal weapons in three important respects. In the first place, the energy from nuclear weapons can be many orders of magnitude greater. The President has spoken about fission weapons of the order of 100 times greater than ordinary weapons. He has spoken about thermonuclear weapons in the millions of tons. So we can speak about nuclear weapons having yields equivalent to millions of tons of high explosive without getting into a classified area at all.

In the second place, when a nuclear weapon detonates, its detonation is accompanied by a very large amount of radiation.

In the third place, when a detonation is over, a considerable amount of residual radioactivity remains on the ground in the neighborhood of the detonation.

In describing such a detonation completely, one should therefore discuss first of all a blast or shock wave. Then one should discuss the thermal radiation, heat, and light which are given out at the time of the detonation. One should then go on to discuss the radiation that proceeds from the detonation, and finally discuss the residual contamination which is left on the ground.

Because of the purposes of this hearing, I intend largely to restrict my comments to the latter two of these subjects.

The release of energy in a nuclear detonation deposits a very large amount of energy in an extremely small region of space. One kiloton—1,000 tons of high explosives—produces a certain amount of energy. That same amount of energy could be given out by the fission of something like a cubic inch of uranium which is about a pound.

So we have a tremendous amount of energy in a real small region of space.

Similarly, in the fusion reaction, the fusion of 1 pound of deuterium could produce an amount of energy equal to that of about 26,000 tons of high explosive. Hence, the initial effect of such a detonation is the rise of temperature of the materials themselves to a very high figure—many millions of degrees—whereas in a normal high explosive detonation, the corresponding temperatures are of the order of 5,000°. Hence, this very high temperature is one of the first effects of a nuclear detonation which is different from that of high explosive reactions.

This extremely high temperature which is not very different from that which exists at the center of the sun is accompanied by tremendous pressures, such that at a very few microseconds pressures of the order of many millions of pounds per square inch exist. An expansion, then, of the vaporized bomb materials begins to take place, and at seven-tenths of a millisecond—that is, seven ten-thousandths of a second—the fireball for a 1 megaton detonation will have a radius of 220 feet, and at about 10 seconds will have reached its maximum diameter of about 7,000 feet. This is for a 1-megaton detonation.

This growth of size is accompanied by a decrease in temperature and pressure, the formation of a shock wave which produces the familiar blast effects, and at the same time the fireball will begin to rise and to engulf large quantities of air and other materials, depending on the way in which the detonation takes place. (See pp. 97–98.)

While the ball of fire is still luminous, fission products, fissionable material, bomb casing, and other materials, are all present in the form of vapor. But as the ball of fire begins to cool, these materials condense; they form little globules in the fireball; they are absorbed on particles of dust and dirt which may be present, and eventually start to fall out in the process which will be discussed for you called fallout.

The cloud from a megaton weapon rises initially at tremendous velocity. Its initial velocity may be as much as 250 miles an hour. Consequently, in the first minute the fireball will have risen to a very great height—as a matter of fact, something like 4 to 4½ miles—and hence the radiation which reaches people on the ground in the vicinity can reasonably be divided into two parts: That part which comes in the first minute, which is sensibly that from the fireball, and that which comes after the first minute when the fireball is so far away that it can no longer have an effect and hence this radiation is from that material deposited on the ground, induced activity, or from fallout.

This distinction is somewhat arbitrary and yet it is a useful distinction, and we speak thus of initial radiation as that which occurs in the first minute, and delayed radiation that which occurs after the first minute.

It might indicate to you, because of this distinction, just how the cloud goes as a function of time. If I list the height of the cloud and the time at which the cloud reaches that height, we will say that

the cloud will be at 2 miles in three-tenths of a minute. It will be at 4 miles in three-quarters of a minute. It will be at 14 miles in about 6 minutes.

Representative VAN ZANDT. It is based on 1 megaton?

Dr. GRAVES. This is all for a 1-megaton bomb.

So when we say that the initial radiation is that which occurs within the first minute, we are saying after that the bomb itself is so far away from us that the radiations from the fireball are essentially negligible compared to other kinds. That is basically the distinction between what we call initial radiation and residual radiation.

Clearly this table will vary for different yields or different atmospheric conditions. But it is an illustration of the height to which the cloud will rise in a given time in order just to make clear the distinction between initial and residual radiation.

Dr. Mills this morning discussed for you the fission process. I would like to repeat, to some extent, the information that he gave, in different language, chiefly because I would like to put a little different emphasis on the remarks that he made.

In the first place an atom may be thought to consist of a central nucleus with a number of electrons rotating around it in various orbits. The simplest nucleus known is that of the hydrogen atom which has a mass of 1 and a charge of plus 1. The hydrogen nucleus is called a proton. All other nuclei consist of protons and particles which we call neutrons. The neutron is just like the proton except that it has no positive charge. It has the same mass but has no charge.

For some reason or other, there seems to be a tendency in nature for nuclei to consist of about equal numbers of protons and neutrons. For example, the helium nucleus contains 2 protons and 2 neutrons. One form of lithium nucleus contains 3 protons and 3 neutrons. Carbon contains 6 and 6. Nitrogen contains 7 and 7. Oxygen contains 8 and 8, and so on. This is a general tendency among nuclei. They are stable when they have roughly equal numbers of protons and neutrons.

In the uranium nucleus, which contains 92 protons and 143 neutrons, it is obvious that this is not the case, because now the number of protons is very much less than the number of neutrons.

In the fission process, therefore, when we split the uranium nucleus we tend to have parts which are very rich in neutrons, and hence in the process we would expect to find neutrons being emitted, or neutrons giving up electrons so that the neutrons are converted to protons. Hence in the fission process we would expect to find neutrons being emitted, we would expect to find beta particles (electrons) being emitted, and we would expect to find energy in the form of gamma rays being emitted.

This is the basic origin for the activity and the radioactivity that is produced in nuclear detonations.

In ordinary chemical reactions, the revolving electrons take part, and they are the things which hold the atoms together to form carbon dioxide, water, salt, and so on.

It is the forces that these electrons produce in one way or another which cause the normal molecular reactions to occur.

In nuclear reactions, it is the nucleus which plays an important part. In the fission reaction we have the uranium nucleus, around this we will have 92 electrons. They are not shown on this chart because they have no importance in the particular reaction we are discussing. (See p. 98.)

The uranium nucleus is struck by a neutron. When the neutron strikes the nucleus, it forms a new nucleus which is a form of uranium but is heavier by 1 unit. It will now be uranium 236.

Uranium 236, then, is unstable in a very strange way. It is unstable in that it tends to split to form two pieces. These two pieces are the fission fragments which we have been discussing this morning and which we will discuss from now on in considerable detail.

In addition to the fission fragments, this reaction also gives off a number of neutrons. The number of neutrons will vary, depending on what the fragments are. It may be 3, as shown here, it may be 2, or it may be 4. But it will vary from one nucleus to another or from one mode of disintegration to another.

You have heard at considerable length of the production of krypton, the production of strontium, the production of barium, the production of many things in this sort of process. What comes out depends entirely on how the split takes place. If you take a piece of paper and tear it in half, the two pieces of paper will never be identical if you repeat the process time after time. Similarly here, the way in which the nucleus splits, depends very much on chance. We may at one time have it split the way we have shown here, but at another time we may have a different set of nuclei.

It turns out that fission can happen in some 40 different ways. That is, we may have 40 different pairs of nuclei produced. These nuclei are all radioactive; they all decay, and in decaying go through a number of different stages of decay. All in all, we may find some 200 different radioactive species present in fission debris. That is, there are the original 40 pairs produced by these 40 modes, and all of their daughters and granddaughters, a total of something like 200 different species of radioactive atoms.

I have another chart which shows the way in which this is done. I have listed on the bottom here the masses of these nuclei. Then up the side are listed the percents formed. This says 10 percent of the fission that occur will produce these elements. One one-hundredth of a percent would produce these. One one-hundred-thousandth of a percent would produce these. (See p. 96.)

What we have done is to try to illustrate the relative frequency with which a given mode of fission will occur. You will notice that in fission there is a strong tendency to produce a light fragment and a heavy fragment, and that there is very little probability of producing symmetrical fission, in which the two fragments would be equal. This figure can vary with a particular fissioning material that you use. This chart is drawn for uranium 235. If we were going to draw it for plutonium we would have a slightly different chart. If we were going to draw it for fast neutrons, we would again have a different chart. But for a specific case this is an illustration of the way, or the many ways, really, in which fission could occur.

One would expect, then, from this particular chart to find that masses in the region of 95—somewhere along in here [point to chart] and masses in the region of 140 or something of that sort, would oc-

cur quite frequently. Hence we would expect that we might have a case where strontium 95 was produced as the light fragment and xenon 139 as the heavy fragment. You notice that this strontium 95 is not the strontium that we were talking about this morning. The strontium this morning was strontium 90. This is strontium 95. It behaves like any form of strontium chemically. You cannot distinguish it from normal strontium chemically. But it is different nuclearly. Strontium 90 has a half-life of 28 years. This form of strontium has an extremely short half-life, of the order of a very small fraction of a second. It decays to yttrium 95, and you will recall that strontium 90 also went to an isotope of yttrium, yttrium 90. Yttrium has a different half-life, and for yttrium 95 is very short. These two half-lives are so short we do not know what they are, but they are each a very small fraction of a second. Yttrium 95 then goes to zirconium, and this goes to columbium or niobium, whichever is the name you prefer, and this finally goes to molybdenum, which is stable.

You notice in this process what has happened in that one of the neutrons in the nucleus of strontium 95 has given up an electron and thus converted itself into a proton. The mass has stayed at 95 all the way through the process, but we have lost an electron in each one of these stages, or we have gained one unit of positive charge.

So when strontium becomes yttrium, we have lost no mass, we have lost a negative charge, and similarly here and here [indicating at blackboard] hence this process which I am describing is accompanied by the loss of four electrons, and at each stage gamma rays will be emitted. That is, this strontium will be in a very excited state. In order to lose its excitation it emits a gamma ray or several gamma rays, so that not only electrons but also gamma rays are emitted.

Similarly xenon 139 will also decay with the production of electrons and gamma rays. It goes first of all to cesium 139. Cesium decays to barium. Barium decays to a form of lanthanum, and this is the stable lanthanum, as I recall it.

Again, let me emphasize that in this particular mode of fission which is one which should be most prominent, we have a net effect of the production of seven electrons, numerous gamma rays, and a large amount of energy. This is just an illustration of what may happen.

Other chains that can occur can be different from this but they will have this similarity, that they will produce electrons and they will produce gamma rays, and in the fission process, neutrons will be emitted. Almost never in the fission process are stable isotopes produced. It just so happens that when a fission reaction occurs, the fragments themselves do not appear in the form of stable nuclei. They are always in an unstable form and try to lose neutrons or electrons to become stable.

However, we do find a type produced which will have only 1 stage, or perhaps 2 stages of decay before becoming stable. Then we will have some which produce very many more. We have several that will produce as many as six. For example, krypton 97 among the light elements, and xenon 143 among the heavy, produce the longest decay chains that we know of. Each one of these has six stages of decay. Each emits six electrons and many gamma rays.

Senator BRICKER. Does the breakdown in krypton follow the same line as it does in the 95 group?

Dr. GRAVES. Yes, it is exactly the same process. You will have six stages. Here you lose one electron—that is, you go from krypton to the next element and so on—you do not change the mass at all. There are a few cases, and only a few, where instead of losing an electron like this, you will lose a neutron. This is a very rare occurrence and is the origin of the delayed neutrons. Almost invariably the decay process is similar to the one given here.

Senator BRICKER. You say that krypton 97 gives off six products in the decay process. What are the additional ones?

Dr. GRAVES. I don't have them here. It ends up again in a form of molybdenum. I can list many of them.

Senator BRICKER. It is the same end result?

Dr. GRAVES. Yes, sir. Instead of being molybdenum 95 it is molybdenum 97. Then there will be niobium, zirconium, and yttrium 97.

Senator ANDERSON. How do you know whether it will be strontium 95 or strontium 97? You end up with strontium and molybdenum 95 which you say is relatively harmless.

Dr. GRAVES. It is stable.

Senator ANDERSON. When do you get to the strontium 90?

Dr. GRAVES. We started out with this element with a mass 95. If we start out with an element of mass 90 right here then we would have ended up with strontium 90. That also is a very prominent member. It happens quite frequently.

Senator ANDERSON. Let me ask it this way, Doctor Graves: Are there any statistics showing how frequently this fissioning results in strontium 90 and how frequently it results in strontium 95 or strontium 97?

Dr. GRAVES. That is what this chart shows.

Senator ANDERSON. That is what that chart shows?

Dr. GRAVES. This says that in about 5 percent of the cases the chain which includes strontium 90 occurs. It may vary from 3 percent to 5 percent, but it is about that number.

Senator ANDERSON. In other words, one-twentieth of the time, you would say?

Dr. GRAVES. Yes, sir.

Senator BRICKER. Is your molybdenum 97 found in nature?

Dr. GRAVES. Yes, sir.

Senator BRICKER. All of the end products of these decaying processes are natural elements?

Dr. GRAVES. Yes, sir.

Senator ANDERSON. Then if there is discussion of bombing and people talk about strontium 90, there is a possibility that several bombs might be exploded and no strontium 90 at all exists.

Dr. GRAVES. As long as fission occurs, the probability is 1 in 20 that roughly 5 percent of the fragments which are produced will be strontium.

Senator ANDERSON. It is a fairly regular pattern that happens in most explosions where a portion of it is strontium 90, a portion is 95, and a portion is 97, but it is a relatively small portion?

Dr. GRAVES. As a matter of fact, when scientists are discussing the things that we do not know, or the things that we disagree on, this is not one of them. Data of this sort—the real input data—is very well

known. The question is on what effect this will have on a human being. I do not want to discuss that. This part is known.

Senator ANDERSON. Cesium 139 has some members of its family that are destructive.

Dr. GRAVES. Yes. Strontium 90 as you recall gives out beta particles. It emits no gamma rays. Hence it is only important if it is inside the body as an ingested material. I am talking out of my field but if it goes to the body it goes to the bones and there it has its effect. Cesium is not that way. Cesium is a gamma emitter and hence it can be important as a part of the external dose. It is a relatively prominent fragment. Cesium is formed in something like 5, 6, or 7 percent of fissions.

Senator ANDERSON. That is what brings me to say that even though strontium 90 is not formed, there may be a strontium figure, which I assume is somewhere around 97, which will produce some cesium 137.

Dr. GRAVES. That is correct.

Senator ANDERSON. And that is somewhat dangerous.

Dr. GRAVES. Yes. As a matter of fact, all of these fragments, as I will discuss in a minute, contribute to a hazard which we call the residual hazard, or what is left over after the detonation. In fact, this is the hazard, the things that are produced here are the things which are giving out gamma rays, beta rays and so on, and which produce the biological changes with which we are concerned.

Senator ANDERSON. So practically up and down that scale you have products that could be harmful.

Dr. GRAVES. Products that are harmful.

Senator BRICKER. What is the half-life of cesium 139? Is it a fast decaying element?

Dr. GRAVES. It is relatively fast. There are only a relatively few that are quite long. Strontium 90 is one of them, being 28 years. Cesium 137 is also long. Those two are the main fragments which are left after times like years. Those are the ones that you have to worry about. The others are all decayed by then.

Senator BRICKER. They are gone in a day or two?

Dr. GRAVES. Not in a day or two, but inside of a year.

Senator ANDERSON. It is because of this half life of strontium 90 that runs 28 years that we talk about it and worry about it more than we do 95 or 97 or any other number?

Dr. GRAVES. Exactly.

Senator ANDERSON. We are worrying about the length of time. The immediate bursts go quickly and then we worry about the long life of strontium 90?

Dr. GRAVES. Yes. It happens that this is exactly the wrong half-life. If it were very short it would be gone so fast we would not worry about it. If it were 1,000 years it would decay slowly. 28 years being comparable with the human cycle is just the wrong period. It has the maximum activity and still present with us for a long time.

Representative HOLIFIELD. Do you intend to get into the factor of the amount of this material that goes into the stratosphere and the amount that is left upon the earth in the initial explosion and the rate of fall from the stratosphere of the amount that goes in? Had you intended to comment on that?

Dr. GRAVES. No. It was my understanding that would be taken care of by the next speaker.

Representative HOLIFIELD. Very well.

Senator PASTORE. How do we know it has a 28-year half-life?

Dr. GRAVES. One can measure it very accurately, Senator Pastore. What we do is to measure the activity today and tomorrow and the next day. One sees it dropping off. So if you have 100,000 disintegrations now—suppose that a year from now you had half as many disintegrations—you would know that half of it was gone. So by following the decay one can determine just how long it takes for half of it to disappear.

Representative COLE. What is the explanation of why some form of strontium has a longer half-life than others?

Dr. GRAVES. It depends on how nearly stable it is. One form of potassium is almost stable. It is just barely over the edge. If it is just barely over the edge it takes quite a time for it to fall off.

Representative COLE. Stability is a substance that has no half-life.

Dr. GRAVES. Exactly. If you were to plot the normal elements, plot the number of neutrons against the number of protons, there is a great tendency for the number of neutrons to equal the number of protons. So among the light elements this is a straight line at 45 degrees. They all have an equal number of neutrons and protrons.

If for some reason or another you produce an element which has a different number of neutrons it is very unstable. If it is closer to this line it is less unstable. Finally when it is nearly on the line it takes many, many years for it to decay. It depends how near it is to this line. If you get up to uranium or the heavy end, this line curves up and you find we have a tendency to have more neutrons. But within, you will have a case like this [drawing curve on blackboard]. Anything within this band is stable. There will be a lot of individual points but they are all within a band like this. Outside of this region they are unstable.

So it depends on how far outside this band they are as to what their half-life tends to be.

Representative COLE. That is not quite it. What is there about a strontium 90 that gives it a comparatively long half-life but strontium 95 a negligible half-life?

Dr. GRAVES. Strontium 95 is just much less stable than strontium 90. It is very far off stability.

Representative COLE. What is there about it that gives it a much less stability?

Dr. GRAVES. Strontium 90 has many less neutrons.

Representative COLE. The difference between 95 and 90?

Dr. GRAVES. Yes.

Representative COLE. Does strontium 95 have the same effect on the anatomy as strontium 90?

Dr. GRAVES. If it were present in you? No. Strontium 95 not only gives off beta rays but it gives off gamma rays, whereas strontium 90 gives off only beta rays. In addition, strontium 90 stays with you for a long time. So it can become fixed in your bones and it can irradiate the material of your bones. Strontium 95 has such a short life that it never becomes fixed in the body. You do not have time to eat it and then have it converted into body tissue.

Representative COLE. If it did stay longer it would have the same effect?

Dr. GRAVES. Or even worse because of the gamma rays it produces.

The fusion process is quite different from the fission process. Among the light elements, there is a tendency for the energy per nuclear particle—that is, per proton and neutron—to decrease with increasing weight as contrasted with the fission process, in heavy elements, where it increases with increasing weight. Hence whereas in the fission process we tend to gain energy by splitting a nucleus, among the light elements we tend to gain energy by combining nuclei—by joining them together—and hence by a process which we call fusion.

Again I may be repeating to some extent what Dr. Mills said this morning, but I would like to list for you the reactions in deuterium which are important from the point of view of fusion because this again illustrates the important difference between the fission process and the fusion process as far as production of radioactivity is concerned.

Whereas in the fission process I have said there might be as many as 40 different modes that can occur—40 different ways in which the fission process can occur—there are only two ways in which the fusion process of deuterium can occur. We may have deuterium joining with another deuterium atom to produce a different form of hydrogen. Deuterium which is a form of hydrogen has a proton and a neutron in the nucleus. The fusion reaction may form still a third form of hydrogen, which we call tritium, where tritium has 1 proton in the nucleus and 2 neutrons.

Tritium plus a proton or helium 3 plus a neutron may be produced.

In each of these cases energy will be produced. In the first case there will be 3.2 Mev. Did Dr. Mills explain this term?

Representative HOLIFIELD. No.

Dr. GRAVES. A million electron volts is the energy an electron would have if it fell through a million volts. If you take it from here and apply a million volts to it, when it gets down to here it will have this amount of energy. It is like saying it has so many foot-pounds of energy, or what-not, but it is a number giving us a measure of energy. In this case we would also produce energy and it would be 4 Mev.

The net result of this fusion reaction, is that we have helium which is stable. We have protons which are simply the nucleii of hydrogen atoms which are stable. We have neutrons. Then we have tritium which is unstable.

Tritium itself may unite with deuterium and if it does it will produce a form of helium—normal helium, as a matter of fact—at mass 4, and it will produce a neutron.

In this case, we have used up our radioactive atom tritium and produced stable helium. Again we have a large amount of energy produced. This produces 17 million volts of energy.

Then finally, under certain circumstances we may have these helium 3 nuclei uniting which will produce helium 4, plus 2 neutrons. This time we will have 11 million volts.

The point that I am making is that in each of these reactions we have energy produced. In the net of all of these reactions we have many neutrons produced, but we have no radioactive materials produced, with the exception of tritium, which is also itself used up in subsequent reactions with deuterium, and this is a very probable reaction.

This, then, is the difference between the fusion reaction and the fission reaction. Although we have also large amounts of energy produced, we have very small amounts of radioactivity produced directly. We may still have radioactive materials produced by action of these neutrons on substances that are present. I will discuss this when I discuss induced activities.

We have now discussed the production of radioactive materials in the fission process, the production of radioactive material, such as it is, in the fusion process.

The third source of radioactive materials is in the induced activities which are caused when these neutrons react with substances that are available.

Chairman DURHAM. Did you say what degree of heat you get in either one of those final chain reactions?

Dr. GRAVES. If you take a pound of deuterium and somehow or another burn it all—that is, burn the whole pound of it—you will get the equivalent of 26,000 tons of TNT. That is the amount of energy that you would get from 1 pound of deuterium. The temperature will depend on how much material you apply this energy to. But this is the amount of energy you would get out of a pound of deuterium burning completely.

Representative VAN ZANDT. That is about 1 cubic inch.

Dr. GRAVES. No. It depends on what form it is. It is a gas. It depends on its pressure. A pound of uranium, I said, was about a cubic inch.

Is that sufficient for your purposes, sir?

Chairman DURHAM. Yes.

Dr. GRAVES. Normally, the radioactive materials induced by neutron capture in dirt or in bomb materials or in air will have a very short half-life, or they will have a long half-life but will have such small energies in their decay particles that they will not be important.

Consequently, we may say that the induced activities are not going to be a tremendously important worry or concern in this problem. For example, nitrogen in the air can capture neutrons to become carbon. It becomes a form of carbon which is radioactive, but it is radioactive with a half-life of 5,000 years. Consequently, although it is around a very long time, and although it may take its place in our bodies, it has very little energy in the particles which come from it. It has very low activity, and the amount that we can produce is extremely small compared to the amount which occurs naturally in nature.

Therefore, radioactive carbon itself is not an important activity.

We may have others, however. Oxygen can absorb fast neutrons and in so doing it forms an isotope of nitrogen which has a half-life of only 7 seconds. Since the half-life is only 7 seconds, within a minute essentially all of this nitrogen will be gone. In 6 half-lives—(I guess that term was discussed this morning)—the amount is reduced to something like 1 percent. In 10 half-lives it will be produced to a tenth of a percent. So in 70 seconds, or a minute and 10 seconds, there will be only one-one thousandths of the nitrogen remaining.

Chairman DURHAM. Do you get a chain reaction, Doctor?

Dr. GRAVES. No, sir. One of the important components of any residual activity will be due to 14.8-hour sodium; 14.8 hours is suffi-

ciently long so that it will be with us for a fair length of time, and yet it is sufficiently short that we will be able to have enough activity to make itself noticed. It is formed when ordinary sodium captures a neutron. Ordinary sodium is present to a very considerable extent in the form of sodium chloride, or salt, particularly if we are in the neighborhood of salt water. We will have large amounts of this type of sodium formed. Again, however, it will disappear in time. Say the half-life is 15 hours—it is a little less than that—this means that in something like 90 hours there will be only 1 percent of it left; 90 hours is roughly 4 days, so that inside of a week there will be very little of the sodium left. Whereas, the fission products will be with us for some time.

Silicon 31 is another one that is formed in very appreciable amounts, largely because there is a considerable amount of silicon present. It is formed when normal silicon captures a neutron. It, however, again has a half-life of only 2.6 hours and hence it decays very rapidly.

Aluminum 28, which again is quite abundant (aluminum is quite abundant—when it captures a neutron it forms aluminum 28) has only a half-life of a few minutes and hence will completely disappear within the first hour.

Chlorine produces a 37-minute activity. This emits betas and high energy gammas but again 37 minutes is so short that it will not be with us for very long.

The only other things that one should mention is that materials of construction, materials which are commonly used, such as zinc, copper, iron, glass, or the salt in foodstuffs, might under some conditions become active enough to become significant.

The net effect of what I have said, I think, is that although induced activities are present, although one can measure them, one can anticipate them, their effect will never be more than a few percent of that of the fission products themselves.

So that in our worries, or in our concern over the activities accompanying atomic detonations, I think it is fair to say that the induced activities are not the important source of radioactive materials or radiation.

Now, if I may leave the subject of radioactive materials and their production——

Representative HOLIFIELD. Before you leave that, Doctor, how do you explain the persistent radioactivity of the coral in the lagoons where these detonations have taken place?

Dr. GRAVES. Largely because there is deposited on this coral fission fragments themselves. When you detonate an atomic weapon on the surface—any surface—you bring up into the cloud large amounts of dust particles. These dust particles are in the cloud along with all of the fission fragments and all the fissioning nuclei, and they are stirred up together and all of the fission fragments must condense from the gaseous form onto something and they condense on whatever particles are there. If we have particles of coral they will condense on coral. In Nevada they will condense on dust particles. So what we have is a coral on which has been deposited fission activity.

Representative HOLIFIELD. So the long-lived activity of materials other than fission materials is caused by the adherence of the fissionable materials to the spectrums of matter, whatever they may be, whether it is dust or coral; is that right?

Dr. GRAVES. Yes.

Representative HOLIFIELD. The matter becomes a carrying element for the fissionable element.

Dr. GRAVES. It is important because it may bring the material down to the ground sooner because it is heavy. In that way it can have an important effect on fallout, as Mr. Kellogg will discuss next. It may also have some activity, like calcium in coral. The calcium of calcium carbonate may become active. Such activities almost invariably decay in such a short time that they may be ignored insofar as the fission-fragment activity is concerned.

Representative VAN ZANDT. Is there any uniformity as to the amount of particles lifted into the atmosphere from a megaton or kiloton of yield of the weapon?

Dr. GRAVES. Yes. You will get an argument from lots of people on this, but my number is that something like a megaton of energy will lift up a tenth of a megaton of dirt. This is rough. It depends a lot on what the dirt looks like and so on, but it is something of that order.

Representative VAN ZANDT. The greater the yield then the higher the particles are lifted.

Dr. GRAVES. That is roughly correct; yes. It depends not only on the yield but the atmospheric condition, as I mentioned before.

Representative HOLIFIELD. In evaluating the radioactivity in a bomb, we must take into consideration the amounts of matter which are contacted by the fireball of the bomb?

Dr. GRAVES. Yes.

Representative HOLIFIELD. It is obvious that, if a fireball is touching the ground or coral reefs or anything like that, it would produce a great deal more radioactive material than if exploded a mile high in the sky.

Dr. GRAVES. No, the difference is not so great. The amount of radioactive material produced will be very little different. It will be some because of the induced activity.

Representative HOLIFIELD. But the dispersion of it, because of its lack of attachment to matter which gravity would have an effect upon, would be completely different.

Dr. GRAVES. That will be completely different; yes, sir, and that is the importance. If you detonate it on the surface of the ground or below ground, then you will have a very strong tendency to have the radioactivity deposited locally. If you put it high up in the air you will have about the same amount of activity. Less will be deposited locally but more will be deposited worldwide.

Representative HOLIFIELD. Is it not true also that the higher you go with the bomb the less you take advantage of its energy release as far as destruction is concerned?

Dr. GRAVES. No, sir. As far as blast effects are concerned, there is a height which seems to be optimum for a given yield. This is not way high up in the air nor on the surface; if you are interested in maximizing blast damage you will pick a certain height. Similarly if you are interested in maximizing thermal damage you will not have it on the surface because on the surface one building will be shielded by another and hence thermal radiation will hit one and burn it completely but will not touch the other. Whereas, if you have it up high you will be able to get both buildings.

Representative HOLIFIELD. But in each case when you go above that set point, you lose efficiency.

Dr. GRAVES. Exactly.

Senator BRICKER. Doctor, you mentioned a moment ago that nitrogen would pick up one neutron and become carbon. That is carbon 14 with the long half-life?

Dr. GRAVES. That is right.

Senator BRICKER. That is the one of Doctor Libby's age determination?

Dr. GRAVES. Yes, sir.

As I mentioned earlier, initial nuclear radiation is defined as that radiation which is delivered during the first minute. I would like to spend a minute discussing initial radiation for you. Although initial neutrons and gamma rays constitute only about 3 percent of the energy of the detonation—that is, 3 percent of the bomb energy comes out as initial neutrons and gamma rays—a very considerable portion of the bomb casualties are caused by these neutrons and gamma rays.

You might compare this with thermal radiation, in which something like a third of the bomb's radiation will come out as thermal radiation. Let me say 33 percent. So here we have 3 percent coming out as neutrons and gamma rays and yet this 3 percent is an extremely important part of the effects that you observe in the detonation.

In order to indicate the magnitude of this effect, I might give as an illustration the following: 50 percent of the people shielded by as much as about 2 feet of concrete would be killed by the initial gamma rays and neutrons 1 mile from a 1-megaton bomb.

Let me put that on the blackboard for you. If I had a detonation of a 1-megaton bomb, and a mile away from that had a shelter whose walls were 2 feet thick, 50 percent of the people in that shelter would die. Whereas, with thermal radiation we could have a very much lighter shield at this same point and provide complete protection. That is why initial radiation is an important part of bomb detonations.

Representative VAN ZANDT. Doctor, how much concrete would be necessary to shield a person from a 1-megaton blast?

Dr. GRAVES. That is just on the edge. If it is 2 feet thick I say about 50 percent of the people would die. If we increase it to 3 feet thick, the chances are that practically everybody would live. This is just on the edge of being sufficiently safe.

Senator PASTORE. That is the question I was going to ask. Why would 50 percent die and not all of them die? Why would 50 percent be vulnerable and why 50 percent not? If you are hit, you are hit.

Dr. GRAVES. It is like when we have pneumonia. Some of us die and some don't. It is partly chance. It is partly how healthy we are. It is partly the condition we are in. This is just the mean lethal dose. This is right on the edge. If it gets much bigger, everybody will die; if it is much less nobody will die.

Senator PASTORE. How do you scientifically assert that? How do you prove that?

Dr. GRAVES. That is hard. The basis for it, however, is experiments with mice or rats, finding out what the mean lethal dose is for a long chain of animals. I would much prefer that you ask that sort of question of a biologist who knows it better. This is the basis for such

a statement. You go on the basis of experiments with animals to find it out.

Senator PASTORE. In other words, we have determined that with animals in blast situations, just as you have outlined, some have died and some have not?

Dr. GRAVES. That is right.

Chairman DURHAM. It is a proven and known fact, Doctor, is it not, that radiation dies in some individuals quicker than in others?

Dr. GRAVES. Some people are more susceptible to damage from radiation, just as in the case of pneumonia. I imagine that is your question.

Chairman DURHAM. The radiation itself dies more quickly in an individual.

Dr. GRAVES. The radiation will depend on the substance. Carbon 14 has a half lifetime of 5,000 years. It does not make any difference whether it is my tissue or yours. Sodium has a half-life of 14.8 hours. There is nothing we can do physically to change that half life. We can heat it up, cool it down, physically distort it in any way we want, but we cannot change the fact that in 14.8 hours half the sodium we have now will be gone. That is just the way radioactivity is.

But the effect of radiation on you may be slightly different from its effect on me.

Representative HOLIFIELD. The effect on a child, for instance, might be much greater than on an adult.

Dr. GRAVES. That is possible; yes.

Senator ANDERSON. Before you get away from the diagram you have there, you show deuterium, plus deuterium, and then doing some other things, and tritium coming in, and you said something about less fission in that sort of operation.

Dr. GRAVES. I said less radioactivity. There are no radioactive materials here except tritium. The tritium itself may be absorbed by deuterium to form normal helium.

Senator ANDERSON. Is there not radioactivity in all fission? In every fission process there is some radioactivity?

Dr. GRAVES. Yes. This fusion and this other is fission.

Senator ANDERSON. In order to have the fusion you are talking about there has to be some fission. I won't say how much.

Dr. GRAVES. This is a fusion reaction but it also can be maintained by heat. If we can somehow or another get this deuterium hot enough it can also be made to react. Hence it is carred a thermonuclear reaction as well as a fusion reaction. One of the ways of getting it hot enough might be to use fission.

Senator ANDERSON. You have not done it any other way, probably, so if you do use fission then any bomb that involves fission will have radioactivity in it.

Dr. GRAVES. I would prefer not to discuss that in an open meeting, Senator.

Senator ANDERSON. That is the trouble. I don't blame you.

Dr. GRAVES. I do not want to discuss how a bomb works.

Senator ANDERSON. I was trying to get around to the claim we have a clean bomb, which I do not believe we have. I did not know whether this was a good place to get it or not.

Dr. GRAVES. I will be happy to discuss that with you personally at any time.

Representative HOLIFIELD. These statements have been made publicly about these clean bombs. I would say this much, without going further into it at this time, that as long as statements have been made that there is a clean bomb some clarifying statement should be made in these hearings.

Dr. GRAVES. I have here a set of processes which involve production of no radioactive materials. I have here a process which involves the production of very large amounts of radioactive materials. As Senator Anderson has pointed out, there is a possibility of a combination of these two processes. If you have a large amount of energy coming from this fission process, there is nothing you can do but produce radioactive materials. If somehow or another you can arrange your geometry or your procedure such that you produce more of your energy from these processes (fusion) then you have less radioactive material for the energy you produce.

Senator ANDERSON. You have a cleaner bomb but you do not have a clean bomb.

Dr. GRAVES. Exactly.

Senator ANDERSON. That is exactly the point. Every time you try to get into a discussion of it—I am not complaining about your attitude on it—we find it is not the best thing to discuss in public, and you are glad to discuss it with me privately and I find it very profitable to discuss it with you privately.

But that does not help the people who read a news story that we have a clean bomb which some of us believe is a true statement.

Dr. GRAVES. I agree with you thoroughly. The statement should be a "cleaner" bomb.

Representative HOLIFIELD. People are being blamed about being confused. Some of the statements that have been made by AEC members and distinguished scientists along this field are directly attributable to part of this confusion that exists. It is the intent of these hearings to clear up some of this confusion, within the limits of declassification. I do not believe that the committee will want to accept everything that we try to do to clear up the confusion, as being classified.

Dr. GRAVES. I do not think one would ask you to do that either. What I would prefer would be to have a chance to discuss this with you privately and let you decide whether it is what you want to accept as classified or whether it is important for your discussions publicly.

Senator ANDERSON. May I say, Doctor, my sole purpose is to try to find out occasionally if there is a chance to clean this up. The only way is to ask witness by witness until we finally come down to a spot where it may be convenient to clear it up. It is not meant to be critical of you in the slightest.

Representative HOLIFIELD. No. This committee is not responsible for the phrase "clean bomb." We are not responsible for it. But there are millions of people throughout the world that may be hanging their hopes upon the fact that we have a humanitarian hydrogen bomb.

Dr. GRAVES. I am afraid the only comment one can make on it is that "cleanliness" is a little bit relative anyway. What you mean by "cleanliness" in this case is a question of degree.

Representative HOLIFIELD. You would not say in this case that cleanliness is next to godliness.

Dr. GRAVES. No. As Senator Anderson says, complete cleanliness is next to impossible to achieve.

Senator BRICKER. May I ask how much earth it would take of ordinary character or texture to give the same radiation shielding that 3 feet of cement would give?

Dr. GRAVES. Yes. It is almost directly proportional to the density. If you have well-tamped earth, something like twice as much earth would be about equally effective.

The initial radiation from all of these radioactive materials or from all of these detonations will consist of alpha particles, beta particles, neutrons, and gamma radiation.

The alpha particles can come from two sources. In the first place, the fissionable materials are radioactive in such a way as to produce alpha particles. So that uranium, plutonium, whatever materials of this sort are present, will produce alpha particles.

In addition, in the fusion reaction we have the production of alpha particles. Here is an alpha particle, here is one, and this would actually be similar to an alpha particle [indicating on blackboard] and there are other alpha particle reactions which are possible.

Neutrons can be absorbed in materials to produce alpha particles. So the two sources are in the heavy materials which are present and in the various alpha-particle-producing neutron reactions which can take place.

As Dr. Mills mentioned to you this morning, alpha particles have an extremely short range. They will scarcely get through the dead skin on the surface of your body, and hence as far as the initial radiation is concerned, are of almost no importance.

Beta particles have a somewhat greater range than alpha particles. They are also produced in large numbers in the various processes that occur. But again they have a short range, such that they cannot reach the ground from an air burst, and within a very short time, when the cloud rises, they will not be able to reach the ground from any sort of a burst, and hence they also are not of great importance as far as the initial radiation is concerned.

Other speakers later will talk about the importance of alpha radiation and beta radiation as far as the internal hazard is concerned and as far as contamination on the skin is concerned. I do not propose to go into that. I would rather limit my remarks to the discussion of gamma radiation and neutron radiation as they effect the initial radiation hazards.

Both neutrons and gamma rays can penetrate air to very considerable distances. They are both highly injurious to living organisms. Hence they constitute by far the most important part of initial radiation.

To a great extent neutrons come out in a very few milliseconds—the first few milliseconds of the detonation—when the bomb will be a very compact, dense material still, and hence these neutrons are very largely absorbed in bomb materials. Enough fast neutrons, however, are present to constitute an appreciable direct hazard at consideraable distances.

Similarly, the gamma rays which are associated with the fission process itself—gamma rays that come out in the initial stages of the fission process—are also present in the stage when the bomb is con-

densed, heavy material, and hence these gamma rays are highly absorbed.

Only about 1 percent of the gamma rays produced directly in fission escape the immediate region of the detonation. However, again this contribution and that of the gamma rays produced in other processes which I will discuss in a minute will produce sufficient intensity at considerable distances to constitute a very real hazard.

Let me mention some of the sources of the gamma radiation which is present in initial radiation.

In the first place it originates in the fission reaction—the one that we picture here.

Second, gamma rays can appear in various neutron reactions.

First, neutrons may be captured with the formation of a highly excited compound nucleus. This compound nucleus loses its excitation—that is, returns to its normal state—by emitting a gamma ray. For example, when neutrons are captured to form carbon 14, in the process of being captured, nitrogen 14 is formed in a highly excited state. This produced two gamma rays which are high-energy gamma rays and emits them. Nitrogen 14 captures a neutron to become nitrogen 15. The nitrogen 15 emits a proton to become carbon 14. But in this process the compound nucleus releases these two high-energy gamma rays.

In the second place, neutrons may react with nuclei, emitting protons or alpha particles, and gamma rays are frequently emitted in this process.

Finally, neutrons may bounce off other nuclei, and they may bounce inelastically such that the bombarded nucleus becomes excited and emits gamma rays.

The third important component or part of the gamma rays in initial radiation is from fission fragments. Fission fragments can be widely spread, and as they decay can give off gamma rays. Many of these gamma rays are given up in the first minute and hence are properly included in the initial radiation.

Although instantaneous and delayed gammas are produced in about equal amounts, the instantaneous gammas are absorbed so strongly that they constitute only about 1 percent of the external dose received. Hence 99 percent of the external dose is due to the so-called delayed gamma radiation. It will probably be of interest to discuss at least briefly the dose distance relationship for both gamma rays and neutrons, that is, how far from a given detonation would someone receive what dose.

Gamma rays lose energy in going through matter by both excitation of atoms and ionization of those atoms. In fact, it is believed that the chemical decomposition of molecules caused by this effect is the major cause of injury to animals and plants. Consequently, the dose of gamma rays is defined and is measured in terms of the ionization produced.

The dose distance relationships for gamma rays and neutrons are very complicated because of the large number of effects involved. Consequently, I would like to ask you to consider what I say from now on in this respect to be quite approximate. It is not possible to write down an exact analytical expression for the dose-distance relationship.

Representative HOLIFIELD. Dr. Graves, are you going to use chart 6 and chart 7 in your presentation?

Dr. GRAVES. I would like to discuss, if I may, the surface burst and the characteristics of an air burst as they relate to fallout. I will use those. Would you like to have me show them?

Representative HOLIFIELD. These are the charts which you furnished us with your statement.

Dr. GRAVES. I will use those; yes.

Representative HOLIFIELD. I think it would be illustrative if you do.

Dr. GRAVES. I will use those; yes.

It turns out that gamma rays going through air will decrease because of distance, and this decrease is a decrease as the square of the distance.

Gamma rays as they go through air will decrease because of many effects. They will be scattered. They will be absorbed. They will lose their energy. But it turns out that the gamma ray dose decreases by a factor of 10 every 780 yards. Consequently, we have a relationship for gamma ray dose which depends on the yield, depends on the distance squared, and then it drops as an exponential which is given by E to the minus D over 338.

$$\text{Formula: Dose}=\text{Const.}\ \frac{W}{D^2}e^{-D/338}$$

This says that dose drops by a factor of E every 338 yeards or by a factor of 10 every 780 yards.

Then there is a constant multiplier. This is an extremely rough formula. For yields from a kiloton up to something like 80 kilotons, it is about correct. If we get much above 80 kilotons, say 100 kilotons, one should multiply the yield by 1½, so it is about 50 percent off there. If one is talking about a megaton, then one should multiply this by a factor of five or something like that. Roughly as far as distance dependency is concerned, the formula can give at least approximate results.

One may do a similar thing for the neutrons. The neutrons again are a constant times the yield divided by the distance squared, and then an exponential term. The neutrons are absorbed more quickly than the gamma rays. The exponential will contain D over 242. If I put it in the same terms that I did for gamma rays, I would say that neutrons decrease by a factor of 10 every 560 yards. So that neutrons will not go as far as gamma rays.

$$\text{Formula: Dose}=\text{Const.}\ \frac{W}{D^2}e^{-D/242}$$

The residual radiation—what is left after the bomb has gone off, after the cloud has gone up in the air and after the fallout has occurred—can also be discussed briefly. In the first place, about a tenth of a pound of fission products are produced for each kiloton of fission energy. The radioactivity at 1 minute would be comparable with that of many pounds of radium. Consequently, a megaton of fission energy would result in activity at 1 minute comparable to that of many tons of radium.

I heard somewhere recently that the total world's production of radium since the beginning of time was something like 50 pounds, so that when we talk about the detonation of a megaton, we are talking

about the production of many times the activity of all the radium which has ever been produced. During the first 24 hours, there would be a decrease by a factor of more than 6,000 in the total activity present and then it will decay continuously. But it has been estimated that if all of these fission fragments from a megaton of energy were spread uniformly over 10,000 square miles, it would cause a radiation intensity after 24 hours of 2.7 roentgens per hour. Consequently, unprotected personnel in that 10,000 square miles would receive more than 300 roentgens of radiation after the first day. 300 roentgens is a lot of radiation. It is estimated that something like 450 is the mean lethal does. So 300 is approaching a lethal does.

Representative VAN ZANDT. Then it would be a uniform distribution over the area.

Dr. GRAVES. That is a uniform distribution over 10,000 square miles which would not happen.

Representative HOLIFIELD. But is it not true that there is no such thing as a uniform distribution?

Dr. GRAVES. Exactly.

Representative HOLIFIELD. This starts at many thousands of roentgens near the bomb and it gradually decreases.

Dr. GRAVES. Yes, sir. Again this will be discussed in the next section of the hearings. I don't want to discuss actual patterns on the ground, but I did want to give an idea of what we are talking about in a rough order of magnitude sort of way.

I would like also to give an idea of the rapidity with which the material will decay. So I will give a table of activity as a function of time. Again let me confine this to a 20 kiloton—a so-called nominal bomb.

At the end of 1 minute, the total activity will be equal to 820,000 magarcuries. A curie is the activity of 1 gram of radium. A magacurie would be the activity of a million grams of radium. So we are saying that at 1 minute the activity would be the equivalent of that of 820,000 million grams of radium.

At the end of 1 hour, this will be down to 6,000 megacuries. At the end of 1 day this will be down to 133 megacuries. At the end of a week it will be down to 13. At the end of a month it will be down to about 2. At the end of a year it will be down to 0.11. Then may I finish this off by saying that at 100 years it will be 0.0006.

This morning you asked Dr. Mills the question, how long would it take this to disappear completely. I could go on for a thousand years and a million years, and I would still get something here, but it gets pretty small. Roughly one can say that for a period of time equal to 7—like 7 days or hours—the activity decreases by a factor of 10. So if we say that the activity at the end of 1 hour is something, then at the end of 49 hours—that is 2 days—it will be down by a factor of 100. In 2 days we have lost a factor of 100. In 2 weeks we will have lost a factor of a thousand. This gives you some idea, I think, of the speed with which this residual radiation will disappear.

Representative HOLIFIELD. In order to be clear on this, Dr. Graves, we are talking about a 20,000-ton bomb.

Dr. GRAVES. Yes, sir.

Representative HOLIFIELD. In the case of a megaton bomb, what is your residual radioactivity danger, and let us go from that and extrapolate it to a 10-megaton bomb. I do not ask for the exact figures.

Dr. GRAVES. We can give them. Let me restrict my answer to those in which the energy comes from the fission process. I don't want to get mixed up in the fusion-fission business again. It will depend exactly on the ratio of yields, A megaton is 50 times as much as a nominal bomb yield. If I multiply by 50, I would get the corresponding numbers for a megaton.

Senator BRICKER. But the time would be the same.

Dr. GRAVES. Yes, sir. I would multiply each one of these numbers by the same factor.

Senator BRICKER. The same ratio of decrease?

Dr. GRAVES. That is right.

Senator ANDERSON. In order to help the record out without making it too damaging, would it not be fair to say, Dr. Graves, that an average megaton bomb at the present time at least would probably not be all fission?

Dr. GRAVES. That is correct.

You have asked that I discuss with you to some extent the partition of energy from a nuclear detonation. I would like to preface my remarks by saying that there really is no correct partition of energy. In the initial stages, we have heat—thermal energy—and in the final stages we have thermal energy. Everything else is thermal initially and ends up as thermal. In between it can be converted into nuclear radiations, shock energy, or thermal radiation. So we are talking about something which is changing and the percentages that I gave are not something which you can say will happen after 2 weeks or at any specific time.

This is a rough estimate [pointing to chart] of the way the energy from a typical air burst will be partitioned. Roughly half of the energy will come out as blast or shock wave. Roughly a third or 35 percent of it will come out as thermal radiation. The initial nuclear radiation—that is, that which comes out in the first minute—is only about 5 percent. Whereas, the residual nuclear radiation, that which comes from deposited fission fragments and from induced activities is about 10 percent. As I say, these numbers sort of interchange back and forth. Blast and shock eventually go into heating up the air and become thermal radiation again. Similarly the residual nuclear radiation, the neutrons and gamma and beta rays come out and heat up the air a little bit, and hence become thermal radiation. So this chart is correct at some time, but the partition of energy changes from the first instance to longer times. Moreover, it depends to some extent on the yield of the weapon, the amount that comes out as thermal radiation might vary depending on what the conditions of the weapon itself are. (See p. 97.)

Representative HOLIFIELD. Dr. Graves, will you explain to me what you mean by "thermal radiation"? Do you mean the heat that goes with the explosion?

Dr. GRAVES. Yes. It is the same sort of energy that you detect when you stand in front of a radiant heater or if you open the door of a furnace. You feel something hot on your face. Those who have been out to Nevada have felt this.

Representative HOLIFIELD. If we talk about the total radiation of the bomb, we are talking about this 15 percent that you speak of here. That becomes 100 percent when you talk about total radiation.

Dr. GRAVES. This 15 percent is the total nuclear radiation. This thermal radiation is something quite different. It is just something because the materials are hot.

Representative HOLIFIELD. In testimony before another congressional committee, Dr. Libby said that in the case of one of these megaton bombs, and I believe it was a 10-megaton bomb he was testifying about, that 25 percent of the radioactivity was the part that caused the downwind pattern of 7,000 miles in the testing grounds of radioactive fallout; 75 percent of it went up into the troposphere and stratosphere. Is that according to your understanding?

Dr. GRAVES. What he was talking about in that case would be the nuclear radiation itself.

Representative HOLIFIELD. Yes.

Dr. GRAVES. Let me say the residual radiation.

Representative HOLIFIELD. Yes.

Dr. GRAVES. We have a large amount of fission activity and induced activity. He was restricting his comment to that. He said that of that, 25 percent in his example was deposited locally, and 75 percent went to the stratosphere. This will change depending quite a bit on how you detonate the device itself. It will change. In his particular example that is how he estimated.

Representative HOLIFIELD. The fact that 75 percent went into the stratosphere did not necessarily mean we were rid of that, because there is a factor of return to the earth, is there not, over a period of years?

Dr. GRAVES. Yes.

Representative HOLIFIELD. Eventually you would get 100 percent of the radioactivity, although your first part would decay.

Dr. GRAVES. You gain a lot if you can put it up into the stratosphere and let it stay up say 100 years. Instead of talking about 820,000 megacuries, you are talking about 0.00006 megacuries. That is a difference. If it is going to decay, let us let it decay 100 miles up.

Representative HOLIFIELD. Has it not been said that it will return in a period of 10 years?

Dr. GRAVES. That is right.

Representative HOLIFIELD. So we cannot talk about 100 years or 1,000 years; we must talk about 10 years.

Dr. GRAVES. Exactly. That is the reason strontium's 28-year half-life is important. If it were a half-life of 1 year, we would not worry about it. It has a half-life long compared to the time it stays in the stratosphere. Hence, still a lot of it is left when it comes down.

Representative HOLIFIELD. So you can say that most of the strontium 90 that goes into the stratosphere would eventually return to the earth, although it would be diffused much greater than that in the local fallout, as you term it.

Dr. GRAVES. Yes.

Representative COLE. Mr. Chairman, I would like to inquire of Dr. Graves, if you are permitted to answer, whether nuclear radiation is a desirable element of a military weapon——

Dr. GRAVES. No one has told me I can't answer that, except I don't know the answer.

Representative COLE. A weapon is for the purpose of destruction. With a nuclear weapon, that is the dazzling light, the heat, the blast and radiation. Those are the four destructive parts of the weapon.

Dr. GRAVES. That is right.

Representative COLE. What I would like to know is whether you feel you can tell us that the radiation phase of a weapon is a desirable factor from a military standpoint?

Dr. GRAVES. I am not told I cannot answer that, but I just don't know the answer. It would seem to me this might also depend on the particular tactics or strategy that are under consideration.

I am not expert on military matters, but if you are interested in establishing a beachhead, you want to be sure you can use that beachhead, so you would not want to put so much activity on the beachhead that you cannot land and utilize it. It would depend on the circumstances of the use of the weapon.

Representative COLE. And whether the nuclear radiation phase is a desirable element would determine the nature of the radiation you seek to create.

Dr. GRAVES. The military situation would certainly be an important consideration.

Representative COLE. What I am thinking is that if nuclear radiation does not have an important military significance in weapons use, I should think that the tendency and your tests and weapons improvement would be to make these weapons as free of nuclear radiation as possible, or in other words, to make them as clean as possible.

Dr. GRAVES. The purpose of our weapons test is to try to find out what we can do with these weapons, such that if someone asks for a weapon which is clean, we will be able to say we know what we can do to satisfy that particular requirement, or if they ask for a weapon with this characteristic or that characteristic. Hence, the weapons test is to give us the knowledge on which we can make an appropriate design to satisfy that requirement.

Representative COLE. Make them either clean or dirty as the military requirements indicate.

Dr. GRAVES. Yes, sir.

Representative COLE. I would hope that some of the other witnesses from the military might discuss that later.

Representative VAN ZANDT. Is it not true that nuclear radiation is contaminating?

Dr. GRAVES. Yes.

Representative VAN ZANDT. Do we not have contaminating weapons in our stockpile at the present time?

Dr. GRAVES. Yes. You mean weapons that are fission. Sure.

Representative VAN ZANDT. Contaminating.

Dr. GRAVES. Yes.

Representative VAN ZANDT. It is common knowledge that military strategists will employ contamination, in the prosecution of a war. They seek to isolate an area through contamination. In addition they might contaminate water for the purpose of producing moisture that would be radioactive.

Dr. GRAVES. I am not an expert on military strategy or tactics so I am afraid I cannot help you.

Representative COLE. It may be true that all of our weapons contain contamination. The question is whether that contamination is in there deliberately or inevitably.

Dr. GRAVES. As I say, if the weapon is designed to make use of the fission process, then that contamination is there inevitably whether the military wants it or not. As I answered you, the object of our tests is to find out whether it must be in there inevitably so that if it should not be wanted, then we would know what to do about it.

Senator ANDERSON. Doctor, in order to clear up any question when you got mixed up with fission or fusion, and my question whether it would be fission along with fusion, the page proof of the booklet, The Effects of Nuclear Weapons, issued by the Atomic Energy Commission, at page 17 has this paragraph. It has been declassified. We have just determined that:

> In order to make the nuclear fusion reactions take place, temperatures of the order of a million degrees are necessary. The only known way in which such temperatures can be obtained on earth is by means of a fission explosion. Consequently, by combining a quantity of deuterium or a mixture with a fission bomb, it should be possible to initiate one or more of the thermonuclear fusion reactions given above. If these reactions accompanied by energy evolution can be propagated rapidly through the volume you have the hydrogen isotope or isotopes, a thermonuclear explosion may be realized.

Therefore, I hope I was not getting outside the properly declassified section when I asked you if, so far at least, we did not have to have a fission explosion in order to have the following fusion explosion.

Dr. GRAVES. I am sure that what we have said earlier was perfectly all right.

Senator ANDERSON. I think it was all right.

Representative HOLIFIELD. Therefore, the conclusion we can reach is that there is a dirty bomb and there is no such thing as a clean bomb, and I am using the word "clean" in the absolute sense and "dirty" in the absolute sense.

Dr. GRAVES. There are dirtier bombs, and some that are less dirty.

Representative COLE. That is correct. It is not a question of a clean bomb versus a dirty bomb. There are varying shades of gray and white in between. It is not one or the other, is it?

Dr. GRAVES. No, sir.

Representative VAN ZANDT. Doctor, can this clean or dirty state be produced in the way you use the weapon?

Dr. GRAVES. Why don't I get into that discussion now? (See p. 99.)

This is the picture of the type of situation which results from a surface burst. In a surface burst of an atomic weapon or a nuclear detonation of any sort, there are two effects that should be mentioned. In the first place, the neutrons that escape from the detonation can strike the ground and hence produce induced activities. In the second place, large amounts of dirt will be mixed up with the cloud, radioactive particles will be plated out on these particles, and hence will tend to fall out more rapidly since these dirt particles will be heavy. So we have, then, here a typical mushroom. It will be very dirty. It will look dirty. You will have nearby fallout of the very heavy particles. At somewhat greater distances we will have fallout of the somewhat lighter particles. Then at very great distances, we will have fallout of the very fine particles.

If this is a relatively small device, very little of the activity will go up into the stratosphere. There is a stable layer in the atmosphere. Again this can be talked about more authoritatively by some of the other people who are present who will be speaking to you later, but there is a very stable layer in the atmosphere which tends to contain such explosions. For the normal small type of device the active material does not get above that, and hence it will all fall out close by, or at least on, say the first pass of the material around the world.

Whereas, from large bursts where the clouds go to very great altitudes, the activity can get up into the stratosphere and this may fall out as much as 10 years later, as Senator Anderson has pointed out.

The difference is that in this particular case we will have very much dirt mixed up with the mushroom. We will have very much close-in and near-out fallout and probably relatively less of the worldwide fallout.

Representative HOLIFIELD. Dr. Graves, before you leave that, you are assuming, of course, perfect test conditions when you make that statement.

Dr. GRAVES. No, sir, I am talking only about the case of a detonation which has occurred on ground. Whether it is a test condition or not.

Representative HOLIFIELD. But as far as the deposit of radioactivity is concerned, you are talking about what you would call safe weather conditions after this explosion, you would have a different situation, would you not?

Dr. GRAVES. I have not been discussing what would happen if you had rainfall or snowfall or that sort of thing, that is right.

Representative HOLIFIELD. That is why you are so careful in postponing your tests, in order to be sure that you have an element of as much certainty as possible with regard to weather conditions.

Dr. GRAVES. Yes.

Representative HOLIFIELD. So that you can get the maximum of protection.

Dr. GRAVES. In the case of testing weapons we try to avoid a situation where the device is detonated on the ground because we don't want to have this very heavy local fallout. We would like to avoid this situation if we can. We try therefore to use towers and make them as high as we can, or we use air bursts as in this chart, or we use balloons for holding the device up. All of this is to avoid getting this mixture of dirt into the cloud itself. (See p. 99.)

Representative HOLIFIELD. It was the purpose of my question to allow you to explain that point.

Representative VAN ZANDT. To take it one step further, suppose that the bomb was detonated under adverse conditions that included a lot of precipitation, what effect would it then have on the fallout?

Dr. GRAVES. Depending on where the precipitation was. Suppose there were a lot of precipitation right at the mushroom, instead of dirt, you would have globules of water which would fall fast. Hence you bring the fallout down faster.

Representative VAN ZANDT. In other words, you add moisture to the particle and make it heavier, and it falls to earth much quicker.

Dr. GRAVES. Exactly. In the case of an air burst, we detonate it high up in the air, and we have two effects. In the first place, there

is relatively little dirt mixed into the cloud and hence there is very little local fallout, very little at the intermediate distances. Practically all of it is spread around over great distances.

In the second pace, since the detonation occurs high up in the air, very few of the neutrons will be subject to capture by chlorine and sodium, calcium or silicon, so that there will be very little induced activity. Most of the activity will be in the form of fission particles and carbon-14 produced by capture of the neutrons in the air.

Then one should realize that there is a possibility of difference here. If you want somehow or another to avoid worldwide fallout the best way to do it is to do it as a surface or subsurface burst. For example, if for some reason we wanted to do our best to avoid fallout over the whole earth, this does it, because this puts most of it down locally. If we want to avoid local fallout, we do it high in the air.

Representative COLE. Dr. Graves, the record does not show which is this and which is that.

Dr. GRAVES. I am sorry. If we want to avoid local fallout and emphasize worldwide fallout, we do it by means of an air burst, the higher burst. If we want somehow to minimize worldwide fallout and maximize local fallout, then we do it by means of a surface burst or a subsurface burst.

Representative HOLIFIELD. That would be in the small kiloton range, would it not?

Dr. GRAVES. It could be either.

Representative HOLIFIELD. If you are going to the megaton range with the fireball touching the earth and with the height of the mushroom cloud, do you not defeat your purpose?

Dr. GRAVES. I am not saying what the purpose is.

Representative HOLIFIELD. I was thinking of a military purpose. The purpose of either having fallout locally or worldwide.

Dr. GRAVES. If we have a megaton weapon to detonate for some reason, if we want to minimize worldwide fallout we must maximize local fallout. Hence we will do it by some such system as this—get as much dirt mixed up in the cloud as we possibly can. If we want to minimize local fallout, no matter if it is a megaton or not, then we go to the air burst because then we minimize the amount of dirt mixed up in the cloud.

The subwater or the underground shots just make this statement more so. If we really want to maximize local fallout, then we detonate these things so deep underground or underwater that nothing goes in the atmosphere, and then it is all local fallout and no worldwide fallout. So if we go from a high air burst down to a case where the fireball touches the ground, and then to where the fireball is on the ground, and then to where it is away below the ground, we are essentially going from a case where there is almost no local fallout, where there is more and more and more local fallout, until finally it is all local fallout.

Essentially it is not fallout at all. It is underground where it stays.

Representative COLE. If that is so, Doctor, if local contamination is a desirable objective of our military, could not that be accomplished by regulating the place where the explosion occurs, rather than to have that contamination contained within the weapon itself?

Dr. GRAVES. All of this is assuming that there is contamination in the weapon. If there is no contaminating material in the weapon, then we won't have fallout anywhere.

Representative COLE. It is impossible to have an absence of contamination in the weapon?

Dr. GRAVES. Exactly.

Representative COLE. A while ago I asked to what extent nuclear radiation within the weapon itself was a desirable military objective. You said it would depend on the local conditions as to whether they wanted to contaminate an area. Now my question is, Cannot that local contamination be accomplished by regulating the height or place where the weapon explodes, rather than having the nuclear radiation contained in the weapon itself?

Dr. GRAVES. The answer is "Yes."

Representative COLE. If that is so, why is not in theory at least the goal of the military to achieve a weapon as free of nuclear radiation as possible and still obtain the blast and heat effect?

Dr. GRAVES. That is the point I was trying to make. If you have a military situation in which you want to contaminate a region very badly, you can't do it by taking a weapon with very little radioactivity in it and detonate it in any way to put fallout down. You have to have the fission products there in order to contaminate the region. Am I misunderstanding you?

Representative COLE. You were not misunderstanding me. I am afraid I am not completely understanding you.

Dr. GRAVES. We have agreed that we cannot produce an absolutely clean weapon. This I think, is clear. On the other hand, there are degrees of cleanliness. If you want to contaminate an area, then let us not pick the lesser degree of cleanliness and try to get activity which is not in the weapon itself.

Representative COLE. In order to have local contamination you must have fissionable products in the weapon itself.

Dr. GRAVES. That is right.

Representative VAN ZANDT. Dr. Graves, earlier this afternoon you said that an air burst at a certain altitude was found to be most effective. Were these conditions that you are now describing taken into consideration in arriving at that conclusion?

Dr. GRAVES. Yes. I said that the height of burst depends on the effect you are trying to produce. If you want to produce the maximum local fallout, then clearly the best place to do it is at or below the surface, or somewhere along in there. If the effect you are trying to produce is the maximum amount of worldwide fallout then the best thing to do is to do it high up in the air.

Chairman DURHAM. You would eliminate most of it by going deep enough in having the explosion?

Dr. GRAVES. If you go deep enough you will contaminate everything right where the explosion occurred. It might be pretty deep for a pretty big weapon, but that is certainly correct.

Representative HOLIFIELD. Of course, this does not take into consideration the strategy or the policy of the military in using these weapons, nor does it take into consideration the policy of an enemy nation in attacking us.

Dr. GRAVES. That is right.

Representative HOLIFIELD. We have no guaranty that an enemy nation will be considerate enough to handle this in a way which will do the least damage, do we?

Dr. GRAVES. No, sir.

Mr. Chairman, I have nothing further that I would like to stress particularly. As I say, I am very happy to have a chance to appear before you and if you have additional questions, I will be glad to answer them.

Representative HOLIFIELD. We appreciate your presentation, Dr. Graves. Will you be with us for the rest of the day in case there are additional questions?

Dr. GRAVES. I would be happy to stay.

Representative HOLIFIELD. Is it according to your schedule to stay? We are not asking you to stay, because we know the important work you are doing.

Dr. GRAVES. No, sir; I have all day today.

Senator HICKENLOOPER. At least while I have been in the meetings, Dr. Graves, there has not been any discussion or comparison of the impact of cosmic rays as compared to other radiating activity or any radiation which might come in from outer space, and how the intensity increases or decreases on that.

Representative HOLIFIELD. That is scheduled for later.

Senator HICKENLOOPER. That is fine. I did not know whether it was scheduled to be discussed.

Representative HOLIFIELD. Mr. Cole.

Representative COLE. Mr. Chairman, I am very hesitant to ask Dr. Graves to continue longer, but since Dr. Graves has been in charge of our weapons tests both in the Pacific and continental United States for the past 6 years or since he is here, it seems to me that it would be of public interest to hear from him the procedures which he and those in charge of the tests followed in order to minimize the consequences of the tests, if he can do so within a few minutes. It is a rather large order, because I am somewhat familiar with the extent of your efforts. But I would like at least to give you an opportunity of telling the public of just what you and your staff do in having the tests occur under conditions which will cause the least damage.

Dr. GRAVES. May I start with the statement of the work which has gone into planning the present series, Mr. Cole, because in my opinion the main safeguards that are introduced into the tests of weapons occur during the planning stages.

In planning the present series, we were faced with the necessity for testing a relatively large number of devices, larger than we had tested before. Hence our planning was conditioned on that particular basis. Since we had to test more devices, we had to be even more careful in this set of tests than we have been in the past. As a result, we went back to the individual laboratories and to the Department of Defense, and told them that some of the tests that they were requiring to be done seemed to us to make the overall operation difficult and asked that they consider their particular requirements to see if somehow or other they could not raise the height of burst, change from towers to balloons, decrease the planned yield, or do such things.

In fact, we also suggested in several cases that the tests be combined so that the data could be obtained from a single test or a single detonation, rather than from two.

We also devised a new method of determining the relative hazards of a particular test by estimating the number of megacuries—the numbers that I placed on the board over there—which would be deposited locally. So that if we have a case where a hundred megacuries is going to be deposited locally, we can be sure that test will be less dangerous than one in which two hundred megacuries would be deposited.

In this way we were able to compare one test with another. We could decide which particular test we should worry about. We could decide whether this series was going in fact to be worse than the next series or the past series or not.

Once we have finally come up with a plan whereby the total amount of fallout is minimized, then we have to come to face with problem of carrying on the tests such that even the fallout that does occur will not hurt anybody. In order to do this, we have assembled in Nevada as competent a meteorological group as one can find anywhere. This meteorological group tells us long in advance what the weather will be like, such that we can control where the fallout will occur.

The test area is in the midst of a bombing range which consists of very many square miles where there is no one. If we can arrange things such that the fallout occurs in this bombing range, then we will be sure of not hurting anyone. In order to guarantee that it will fall in the bombing range, we have to know what the weather is going to be like. The postponements that have occurred for the last 10 days or so have all been due to 2 facts. In the first place, we have had unusual high winds. We have had a jet stream coming through which could carry the material to great distances, and that we do not like. We would rather have the fallout occur on our bombing range. In the second place, we have had a lot of precipitation. I know those of you who have been out there with us realize that we have been on a desert, but you may be surprised to find out that a few days ago our meteorologists told us there would be scattered showers in the region in the desert. We said let us not shoot while we have showers. I went into town that night to tell the newspaper people why we had this postponement, and I almost drowned getting back out. There was a flood. The highway was covered with water, and we had 6 inches of water in our ditches in the desert.

The next day they told us we might have some snow flurries. We had snow out on the desert. All these conditions are not feasible for tests because they sweep down the radiation and put it on the ground in regions that we can't control.

Consequently, I would like to give a very considerable hand to this group of meteorologists who we have out there who may make us mad because they make us postpone, but they keep us out of trouble. They tell us the weather with great accuracy and permit us to be sure that the weather will not give us a fallout situation that we would not like.

I am often asked the question, why is it that we don't do all of these shots by high airburst. We discussed here the possibility of minimizing local fallout by using high airbursts. The conditions of testing are largely the conditions pertinent to the information we want to

get. We are not interested in producing there, information such that if someone says to make a weapon, then the laboratories will have the information they need to make that weapon. It turns out that there are experiments that must be performed to get some information in which the position of the device must be known with extremely great accuracy.

I may say that we have an experiment proceeding in which the position of the device to better than a half inch is required. Clearly this sort of accuracy is impossible from an air burst. It is even impossible with a device suspended from a balloon.

There are other cases where we don't care where the device is to a half mile or something of that sort. We just don't care. In such cases, I think we would be very wrong if we did not arrange somehow or other to detonate these devices high up in the air by an air burst.

So what we do is to then say our laboratories have certain requirements. They require us to test certain devices. They require us to get certain information from those devices. Our job in Nevada and in the Pacific is to devise a plan whereby these tests can be made and these experiments done safely.

Representative COLE. There is only one other question. What has been your experience with respect to radiation damage that has been the consequence of tests during the time you have been Director, limiting it to the tests in Nevada.

Dr. GRAVES. Again a part of the planning activities before this last series of tests was to accumulate all of the known data, all of the data from previous tests, to accumulate all of the measurements which have been made, and to interpret these as best we could into the total dose in all of the communities around the Nevada test site. These doses do not mean that the people in these communities got those doses, but it does mean that a certain fence post would have been exposed to that particular dose, and if someone stayed near that fence post he would have gotten that dose.

We looked at it and the best we were able to determine is that in the region which is now inhabited, the highest accumulated dose would have been something like 4.5 roentgens in the 6 years we have been there. This is something less than 1 roentgen per year. I am speaking from memory so don't hold me too firmly. I think there was one place with 4.3 roentgens. I don't remember now the name of the town. There was one with 4 roentgens. But the great majority were less than 4 roentgens. I am eliminating one place known as Riverside Cabins, where no one is actually living now. The people who were living there were living there for 1 year, as I recall it. The infinite dose to those cabins if somebody had lived there forever would have been something like 7 roentgens. This was the only place that I know of that received more than this 4.3 I have discussed.

Representative HOLIFIELD. Thank you very much, Dr. Graves. We appreciate your testimony.

Our next witness is Dr. Frank Shelton, of the Armed Forces special weapons project.

Dr. Shelton, will you come forward and take the right hand chair.

STATEMENT OF DR. FRANK SHELTON, TECHNICAL DIRECTOR, ARMED FORCES SPECIAL WEAPONS PROJECT [4]

Dr. SHELTON. The material presented to you by Dr. Graves was coordinated with me, and I concur in the statements that he has made to you. To a large extent I feel that the material was gathered and in part reflects the material in The Effects of Nuclear Weapons, the publication which some of you have before you. That being the case, the material as presented I would consider representing an official Department of Defense and Atomic Energy Commission position regarding the accuracy of the material.

I believe that is about all I have to say.

Representative HOLIFIELD. Dr. Shelton, you know that this page proof was only delivered to us I think late Friday, and we have not had a chance to even begin to read it.

Dr. SHELTON. Yes. I was informed this morning that the AEC had made copies available last week.

Representative HOLIFIELD. Therefore, we are not in a position at this time to question you on that particular book. You have no other statement to make?

Dr. SHELTON. I might mention a few words about the organization which I represent. The Armed Forces special weapons project, among other people, helped to prepare the book you have before you. It is the organization within the Department of Defense which would have primary responsibility during the weapons tests to obtain weapons effects data, principally for the Department of Defense. However, we have obtained a good deal of material at the request of the Atomic Energy Commission. We have, for example, been the organization which would gather together the capability of the country to measure the fallout from such an operation as the last Pacific one.

Representative HOLIFIELD. The only thing I can say then, unless there are some questions, is that the staff and the members will have to look at this before we present any questions to you. It is possible that we will call you back later.

Dr. SHELTON. Yes. What I had in mind saying was that I thought Dr. Graves had worked up a very complete presentation for you. I thought it would be somewhat redundant for me to elaborate further. Finally, that much of the material that he presented to you is material which we have already coordinated on and is the official position on the part of the Department of Defense.

Chairman DURHAM. Doctor, give us the size of the composition of your organization, and how you operate. Do you operate in connection with the Los Alamos Laboratories and all the rest of the laboratories throughout the country?

Dr. SHELTON. The Armed Forces special weapons project, as I said, is an agency of the Department of Defense. Essentially we work for the three services, the Army, the Navy and the Air Force, and it is our job to obtain the effects data that they require in the employment

[4] Technical director of the Armed Forces special weapons project. He has been active in the atomic-energy field since 1952. During the spring of 1955, he served as technical adviser to the Military Effects Test Group at Operation Teapot, and in 1953 participated in Upshot-Knothole. Dr. Shelton was born in 1924. He received his bachelor of science, masters, and doctor of philosophy, all in physics, from the California Institute of Technology. Prior to joining the Armed Forces special weapons project, Dr. Shelton was with the Sandia Corp. in the weapons effects field. (Submitted by Department of Defense.)

or anticipated employment of nuclear weapons. To get that information we must participate on the full-scale weapons tests. To do the job, we have called upon many of the Government laboratories, and a number of the civilian laboratories to actually go into the field and to obtain the data.

The Armed Forces special weapons project would then have as its job the assembling of that group of people. We actually coordinate that effort, and guide those people in the field to obtain the required data.

Chairman DURHAM. You tell the weapons division at Los Alamos or Livermore the type of weapons you want?

Dr. SHELTON. It is usually not that way. More nearly the case is that they are detonating a particular type of weapon in the process of development. In a more normal case, we would be aware of that type of weapon and need for information from that type of weapon. We do not tell them the type of weapon.

Chairman DURHAM. You suggest through the military channels what type of weapon you desire. Isn't that the procedure. That is, for whatever size mission?

Dr. SHELTON. Yes, sir. There are broad characteristics required by the Department of Defense in the weapons which eventually would be stockpiled.

Chairman DURHAM. What part do you take in evaluating the tests after they have already been completed?

Dr. SHELTON. When a test has been completed and we have obtained the data in the field, AFSWP continues to monitor the agencies that have taken that data, and in the final production of the reports. One of our largest functions is production of final test reports, on the effects, and not the develcpment of weapons.

Chairman DURHAM. Do you go into the hazard at all of the radiation fallout or does that rest entirely in the laboratories?

Dr. SHELTON. Our large participation in fallout has been pretty well confined to the local fallout. For instance, in the last Pacific tests, we did document many thousands of square miles of the ocean. It was the AFSWP that documented the local fallout in the last Pacific tests.

Chairman DURHAM. Do you have any contact with NATO or the Far Eastern organization SEATO?

Dr. SHELTON. In addition to obtaining the information on weapons effects, we do transmit to the services that type of information in various publications. Those various publications are distributed to the American portion of NATO. Of course, there is the classification problem again. Typically one of our best known publications is one called Capabilities of Atomic Weapons. This is a compilation of the effects as we best know them. That is distributed to all of the Armed Forces of the United States.

Representative HOLIFIELD. Dr. Shelton, do you have or can you present to the committee an unclassified list of the tests which we have held and an estimate of the radioactive mission of those tests? Is that permitted?

Dr. SHELTON. You are asking for a compilation of the tests in chronological order, and you are asking for the amount of radiation produced on those tests?

Representative HOLIFIELD. I am asking you if that can be given to the committee on an unclassified basis or not?

Dr. SHELTON. I have discussed this subject, prior to coming here, with members of the AEC. We feel that we could not do that. We could do it in a closed session.

Representative HOLIFIELD. I understand that.

Dr. SHELTON. We feel that it would reveal information of a sensitive nature.

Representative HOLIFIELD. In this book which I have not had a chance to read yet, you do not go beyond the description of explosion of one weapon, let us say. There is no extrapolation of what would occur in a war if 100 weapons of a megaton or 5 megatons each were exploded on the United States?

Dr. SHELTON. What you have said is essentially correct. The phenomena as presented are over varying yields, but presented as one shot at a time and the effects that you can expect. The only effect, of course, that would be additive in a real large sense would be the fallout. In the normal employment of weapons one would not typically overkill his target by repeatedly blasting weapons in the same spot. We did not treat the fallout except on a one-shot basis.

Representative HOLIFIELD. I notice on page 419, you have a description of a 1-megaton surface burst with a pattern of radioactivity, and the number of miles involved, the number of hours involved for downwind distribution at the rate of 15 miles per hour wind. It would be possible, by extrapolation, however, to take that particular description and apply it to 100 or 200 weapons if you know the meteorological conditions as of a certain time.

Dr. SHELTON. What you have said is essentially correct. Although the chart given is for the dose rate at 1 hour, for a 1-megaton weapon, one finds the prescriptions given here, the mechanics of getting the same pattern for any other yields. We were not so explicit in giving you the pattern for other winds. As you saw, it was a uniform 15-mile-per-hour wind at all altitudes. I believe Dr. Kellogg, who is to follow us, will give you varying winds, but we feel that the fundamental areas involved are represented by the chart and the prescriptions given for other yields.

Representative HOLIFIELD. As a matter of policy, you do not believe that we should keep from the American people the effects of atomic or hydrogen weapons, do you?

Dr. SHELTON. Indeed not, sir. We have gone out of our way, for instance, in presenting the book that you are talking about and go just as far as we could go. In fact, many of the statements in the book required careful consideration of classification and the final determination that in the interest of the public that was the proper thing to do. We have withheld perhaps only a small percentage of all that is now known about nuclear weapons which is in the sensitive area relating to design of weapons.

Representative HOLIFIELD. You are presenting this book for the committee's action if they so desire of including it in the record, are you not?

Dr. SHELTON. The advanced copies of The Effects of Nuclear Weapons were distributed to the committee by the AEC. Any portions of that book for the record are perfectly all right. I noticed that the book

as I have it here does not have the preface, and I believe that would have explained the role of AFSWP in the preparation of the book. There is a preface and acknowledgment that I presume will go into the final publication.

Chairman DURHAM. Your division prepared this entirely?

Dr. SHELTON. Our division prepared this book in cooperation with Dr. Glasstone, and with the cooperation of the Atomic Energy Commission. We were asked to help prepare the book, and we did.

Representative HOLIFIELD. General Starbird, do you wish to add anything to what Dr. Shelton has given to us today?

STATEMENT OF GEN. ALFRED D. STARBIRD, DIRECTOR, DIVISION OF MILITARY APPLICATION, ATOMIC ENERGY COMMISSION [5]

General STARBIRD. I have nothing specific to add, sir.

Representative HOLIFIELD. You have not prepared formal testimony?

General STARBIRD. I had prepared, Mr. Chairman, some testimony originally when I thought I was to be the first witness. That testimony has been made available to you. It is entitled, "Testimony Before the Joint Committee on Atomic Energy on the Production of Radiation and Radioactivity From Nuclear Weapons." Knowing that Dr. Graves would be available, I consulted with him. I do know that the information contained in the statement that I mentioned has Dr. Graves' concurrence. I find that he has covered verbally everything that is in the statement and in somewhat more elaboration. I would like to request, therefore, that the statement be added to the record.

Representative HOLIFIELD. Thank you. It will be accepted without opposition.

(The statement referred to follows:)

TESTIMONY BEFORE THE JOINT COMMITTEE ON ATOMIC ENERGY ON THE PRODUCTION OF RADIATION AND RADIOACTIVITY FROM NUCLEAR WEAPONS

TOPIC V

1. In this, the 5th topic of the hearing before your committee, we have been asked to cover the Production of Radiation and Radioactivity with Nuclear Weapons. From earlier witnesses you have received general background information on radioactivity and its effect, together with a description of the two basic nuclear processes (fission and fusion). For this topic we have been asked to discuss the nuclear process employed in weapons, to describe the several different physical effects which the explosion of a nuclear weapon would give, and to discuss briefly the division of radiation energy which would result from various conditions of firing. We have prepared a written statement covering these matters and I shall follow closely that statement in my oral presentation.

Description of nuclear weapons

2. An explosion is the release of a large quantity of energy in a short interval of time and within a limited space. The release of this energy is accompanied by a very great increase in temperature so that the products of the explosion become extremely hot gases. The expansion of the air heated by a nuclear

[5] Date and place of birth: April 28, 1912; Fort Sill, Okla. Education: Bachelor of arts, U. S. Military Academy, 1933; civil engineering, Princeton Engineering College, 1937. Work history: Troop duty, Fort Belvoir, 1933-37; company officers' course, Fort Belvoir, 1937-38; instructor of the Engineering Department at the USMA, 1938-41; Operations Division, War Department, General Staff, 1941-44; engineer combat group commander, Third Army, 1944-45; Operations Division, War Department, General Staff, 1945-46; Deputy Chief of Staff, USARPAC and Joint Task Force 7, 1946-49; Weapons System Evaluation Group, Office of Secretary of Defense, 1949-50; area engineer, Corps of Engineers, Pierre, S. Dak., 1950; Secretariat, SHAPE, Paris, France, 1950-53; Office, Chief of Engineers, 1953-55; Director, Division of Military Application, AEC, 1955. (Submitted by the Atomic Energy Commission.)

detonation causes the formation of a blast wave. When the head of the wave (the shock front) passes a given point it results in an abrupt rise in pressure causing some of the destructive effects of the explosive.

3. The nuclear bomb is similar to the more conventional high explosive bomb in that a portion of its destructive action is due to the blast or shock discussed above. However, apart from the fact that the nuclear bomb can be many thousands of times more powerful than the largest TNT bomb, there are other more basic differences. Firstly, a fairly large portion of the energy from a nuclear explosion is emitted in the form of light and heat. This emission is referred to generally as the "thermal radiation." It can cause fires or skin burns at considerable distances. Secondly, the explosion is accompanied by highly penetrating, but invisible, rays called the "initial nuclear radiation." Finally, the substances remaining after the nuclear explosion are in large part radioactive, emitting similar nuclear radiations over an extended period of time. This later radiation, arbitrarily taken as that which occurs later than 1 minute after the bomb's initiation, is commonly referred to as the "residual nuclear radioactivity."

4. Earlier nuclear weapons made use only of the fission process in the achieving of this high energy nuclear detonation. In this process neutrons are caused to enter the fissionable nuclei of atoms of either uranium or plutonium. Under certain prerequisite conditions the fissionable material is split (or fissioned) into fission products by an almost instantaneous chain reaction. During the fissioning, great quantities of energy are released. Neutrons and gamma rays escape from the fissioning material and bombard surrounding elements, forming some radioactive isotopes. The fission products which result from the explosion constitute a very complex mixture. This mixture may consist of about 170 different types of fission debris which are isotopic forms of some 35 different chemical elements. (See chart I.) This fission debris initially is highly radioactive and decays over a period of time by the emission of beta particles and gamma rays. From each kiloton of fission yield approximately one-tenth of 1 pound of radioactive fission products can be expected to occur. At 1 minute after the explosion, when the residual nuclear radiation has been postulated as beginning, the radioactivity from the fission products of a kiloton of fission energy yield is comparable to that of some 100,000 tons of radium. The radioactivity decays rapidly. For example, there are given below the estimated total gamma activities of the fission products from a nominal atomic bomb, expressed in megacuries, at various times after the detonation.

Total gamma activity of fission products in megacuries

Time:	Activity	Time—Continued	Activity
1 minute	820, 000	1 month	2. 3
1 hour	6, 000	1 year	. 11
1 day	133	10 years	. 008
1 week	13	100 years	. 0006

5. Later, means were found of using the fusion process to secure weapons of higher yield than were practical from the purely fission designs. You will remember that a fusion process is the uniting or fusing of very light elements to form heavier elements and that great quantities of energy are given off in the process. To initiate a fusion process tremendous heat is required. The term "thermonuclear" results from the fact that such weapons use heat to maintain the nuclear reaction. In contrast to fission, no fission product radioactivity results directly from fusion. Fusion, however, is accompanied by the escape of neutrons, some of extremely high energies, and these can induce radioactivity in materials with which they come in contact. Naturally, too, in a thermonuclear weapon the fission portion of the reaction forms radioactive debris in the same manner as in a purely fission weapon.

6. The partition of energy from a nuclear explosion as between blast and shock, thermal radiation and nuclear radiation varies somewhat with the design of the device and with its condition of firing. As a general approximation nevertheless, the division can be considered as that shown by chart II. The chart portrays specifically the result which could be expected from the detonation of a device of yield of 1 megaton, fired within the earth's atmosphere, but at such altitude that comparatively little extraneous material from outside of the device is available to be made radioactive by escaping neutrons (as for example, if fired at a few thousands of feet in the air).

7. You will note that in this case some 50 percent of the energy would be released as blast or shock, some 35 percent would occur as thermal radiation (heat or light), while some 15 percent would be in the form of nuclear radiation. Of

this 15 percent, roughly one-third would be "initial radiation" occurring within 1 minute after firing, while two-thirds would be "residual radiation." The highest intensity of this residual radiation naturally would occur during the seconds immediately after the first minute. It would decay rapidly thereafter but some small residual radioactivity could be expected for many years or even thousands of years after the detonation. (See table in paragraph IV.)

8. The 50 percent of the energy translated into blast or shock would have effects quite similar to those to be expected from a high explosive detonation. (See chart III.) These would consist of a shock front (the head of the blast wave), a later region of high and low pressures behind the shock front, and a violent wind flow. This latter would initially be in the direction outward away from the explosion, but later in a reverse direction. The damage caused by the shock or blast would be, of course, a function of the weapon's yield, of distance from the firing and of the strength of the receiver. In the case of a typical air burst, the distance to which a given overpressure (or blast effect) extends varies generally as the cube root of the yield. The term "generally" is used for the reason that there are other factors such as reflected or refracted shock waves and pressures which under many conditions can reinforce or interfere with one another in such manner as to change materially the blast effect at a given point. As an indication of the order or magnitude of the effect one might expect from this phenomenon the burst of a 20-kiloton weapon at an altitude of several hundred feet could be expected to destroy beyond economical repair a multistory reinforced concrete building at distances up to one-half mile. On the other hand, a 1-megaton burst fired under comparable conditions could be expected to give similar damage to the reinforced concrete structure at distances up to 2 miles. Although large pressure differences result in injury to the human body, persons are more likely to be injured by flying objects, crushed or buried under buildings, or thrown against fixed structures than to be injured directly by wave overpressures.

9. The one-third of the weapon's energy emerging in the form of thermal radiation is contained initially in a relatively small volume of incandescent gases resulting from the vaporization of components of the device and of the adjacent atmospheric or other materials. (See chart IV.) This intensely hot spherical mass termed the "fireball" is visible for a perceptible period of time until the thermal radiation has been dispersed over such volume that visible light is no longer emitted. The initial temperature of the fireball is of the order of several million degrees and the thermal radiation covers a broad spectrum of wavelengths and includes ultraviolet, visible, and infrared. These radiations travel outward at tremendous speeds. The extent of injury or damage to a person or material resultant from thermal radiation is a function mainly of total energy received, but secondarily of the rate of absorption. From a given weapon, or from weapons of comparable energy yield, the intensity of thermal radiation received is a function primarily of distance from the burst. The amount varies inversely as the square of the distance, provided there were no attenuation by the atmosphere. The period over which thermal energy is given off from an explosion increases with the yield—that from a kiloton device being limited to a few tenths of a second but for a megaton device the period may extend to several seconds. A 20-kiloton burst could be expected to ignite combustible house materials at ranges up to 2 miles, while a 1-megaton burst could have similar effect up to 10 miles. The 20-kiloton burst could cause first degree burns to exposed skin surfaces at ranges of 3 miles, while a megaton burst could cause similar burns at 14 miles. Adverse weather conditions can vary the distance at which these effects occur.

Nature of the nuclear radiation from a weapon

10. The 15 percent of the weapon's energy which becomes nuclear radiation is the result of several actions and interactions. Some of these, of course, occur immediately after firing while others are much later in the chain. To name the primary of these actions (chart V):

(*a*) Firstly, the initial fission or thermonuclear reactions emit high gamma and neutron fluxes.

(*b*) Secondly, radioactive debris products result from the fissioned atoms. The radioactive debris products condense into particles of various sizes and may fallout locally or at a distance depending upon their size and the altitude from which they fall, as well as meteorlogical conditions. The individual radioactive isotopes regain their nuclear stability by giving off beta particles, which in a large fraction of the cases is accompanied by emission of gamma radiation. The average time for the atoms of a particular isotope

to reach stability varies from a fraction of a second to thousands of years.

(c) Thirdly, neutrons contribute to the residual radiation by inducing activity in various elements of the materials in the bomb, atmosphere or in substances which may be in the explosion environment.

11. Essentially all neutrons escaping a bomb are released from the fission or fusion reaction of the bomb's nuclear material. They emerge almost immediately after initiation of the firing. Though they represent only a very small portion of the total energy yield of the explosion they can possess a sizable kinetic energy. They can penetrate relatively long distances through the atmosphere (of the order of several thousand feet near sea level) and can induce radioactivity in the atoms they encounter. The distance at which the neutrons from a nuclear explosion can in themselves constitute a hazard is a function of the type of reaction, of the size of the explosion, and of the materials surrounding the bomb. From thermonuclear reactions, neutrons of higher energy are released than from the fission process. On the other hand, the number of neutrons escaping to travel to great distances depends on the thickness and type of material which surrounds the nuclear constituents of the bomb.

12. Gamma radiation, like neutrons, is released in large quantities from the initial explosive mass and can pentrate considerable distances through the air. Further, additional quantities of gamma radiation can result from the interaction of escaping neutrons with particles they encounter, and from the subsequent decay of radioactive elements throughout their life. A sizable portion of the residual radiation from a nuclear explosion is released ultimately as gamma radiation. This release is of decreasing intensity with time, but can continue for many years.

13. Two other forms of residual radioactivity alpha and beta particles, are found normally in bomb debris. The alpha particles are of very short range and result only from the unfissioned portion of the original fissionable material. If the fissionable material is available in sufficient quantity and is taken internally into the body, the alpha radiation from it could (with long residence in the body) cause extensive damage. However, for various reasons which will be discussed under a later topic, this unfissioned material is generally less of a hazard than some of the fission products. Beta particles (electrons) have a limited range. Depending upon the initial energy, the range may be only a few centimeters in atmosphere at sea level. Such particles result from the decay of fission products. They can constitute a hazard, but only when deposited on the body's surface or internally.

Type of weapon bursts and their effect on radioactivity

14. The portion of a bomb's energy that emerges as radioactivity (as contrasted to that portion which emerges as blast or thermal) is a function primarily of bomb design. Naturally, if the fission yield is high in contrast with the fusion a greater relative quantity of fission debris products will result. Naturally, too, the higher the energy of the escaping neutrons and the greater the amount of material close to the explosion, the greater will be the induced activity.

15. The conditions of the firing of the weapon, however, can have an important effect both on the amount of total residual nuclear activity and importantly on the distance at which that activity can be felt. In this connection, I shall mention briefly and generally the changes in residual radioactivity distribution which could result from weapons or devices fired on the earth's surface; at several hundreds or several thousands of feet in the air; underground; or underwater.

(a) In the case of a surface or near surface burst (chart VI), a large quantity of the surface material could be drawn up into the fireball to be mixed there with the radioactive fission products while those products are still in gaseous form. Escaping neutrons encountering this drawn up material could induce radioactivity therein. At the same time, however, when the cooling radioactive gases condense they would form in part larger particles which would trap (or scavenge) the material's residual radioactivity. These larger particles would fall out rapidly and relatively close to the firing point from such a burst, thus making local fallout heavy.

(b) In the case of an air burst at several hundred or several thousand feet altitude (chart VII) where the fireball does not touch the ground, the debris from the fission process would be unchanged in amount from that of a low altitude burst. However, the induced activity caused by the interaction on particles sucked into the fireball from the surface would be lacking. The total radioactive debris then would be less than in the case of the surface burst. The scavenging material from the earth's surface also would be lacking. The particles into which the debris condenses would generally be

smaller than in the case of a surface burst and would drift to the earth's surface at a distance from the firing.

(c) In the case of an underground or an underwater burst it is theoretically possible to place the detonation at such depth that little or no radioactivity would reach the atmosphere. Naturally, for such firings the induced activity would be relatively high, but would be confined in the earth or water along with the bomb's debris fragments. In the case of underwater shots, the movement of their residual radioactive particles is affected by ocean currents. In the case of underground burst, however, movement could only be through transfer of the surrounding material to the outside or by leaching. Great depths would be required to confine weapons of multikiloton or multimegaton yield if total initial radioactivity is to be confined.

Measurements and limitation on the data

16. In each of our several test series we have devoted a great deal of effort to the securing of information on the effects to be expected from nuclear weapons. Certain information can be readily secured and other is most difficult to measure or estimate.

17. We have available detailed information on the blast and shock effects to be expected from weapons of various sizes, on various type structures, under different conditions of firing, and different ranges. These data present rather precise estimates of what could be expected from a future detonation or detonations. The same is true, but to a somewhat lesser extent, with respect to thermal radiation.

18. With regard to nuclear radiation we have devoted intensive effort and with all means available to date to the securing of essential information. We can estimate with a fairly high degree of reliability the initial radiation which will result from a certain firing. With respect to residual radiation, because of the time over which it will occur and the many factors (including atmospheric) which have effect, the giving of precise forecasts is much more difficult. I shall not attempt to cover these factors, nor their reliability, in view of the fact that many of the later witnesses will give expert testimony in this regard.

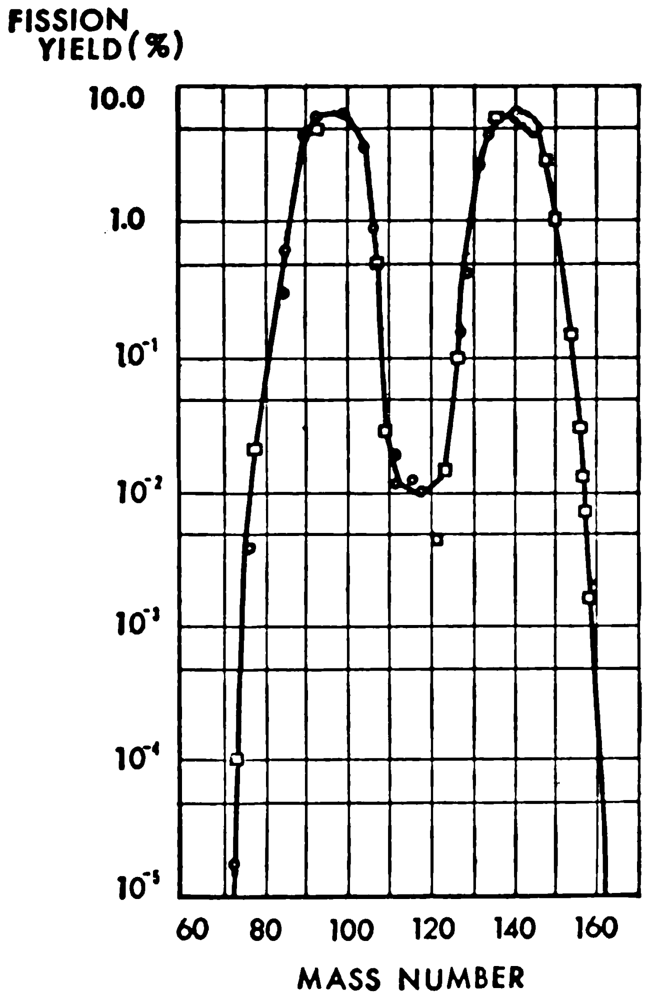

CHART I.—Fission yield versus mass number of fission products.

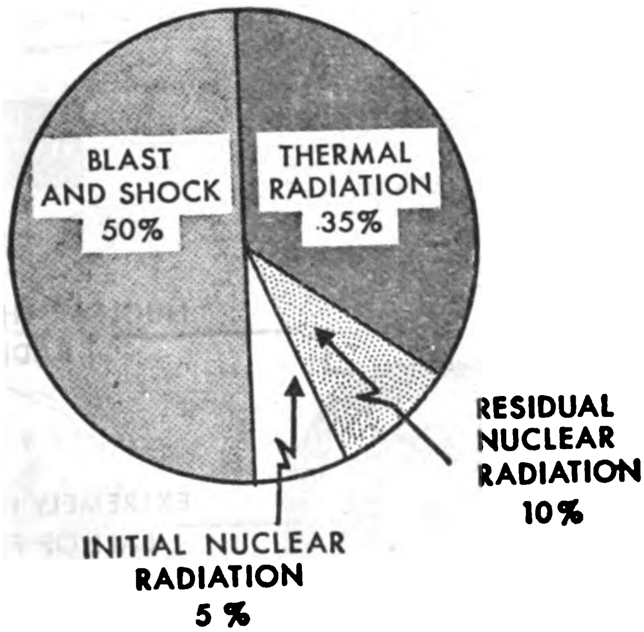

CHART II.—Distribution of energy in a typical air burst.

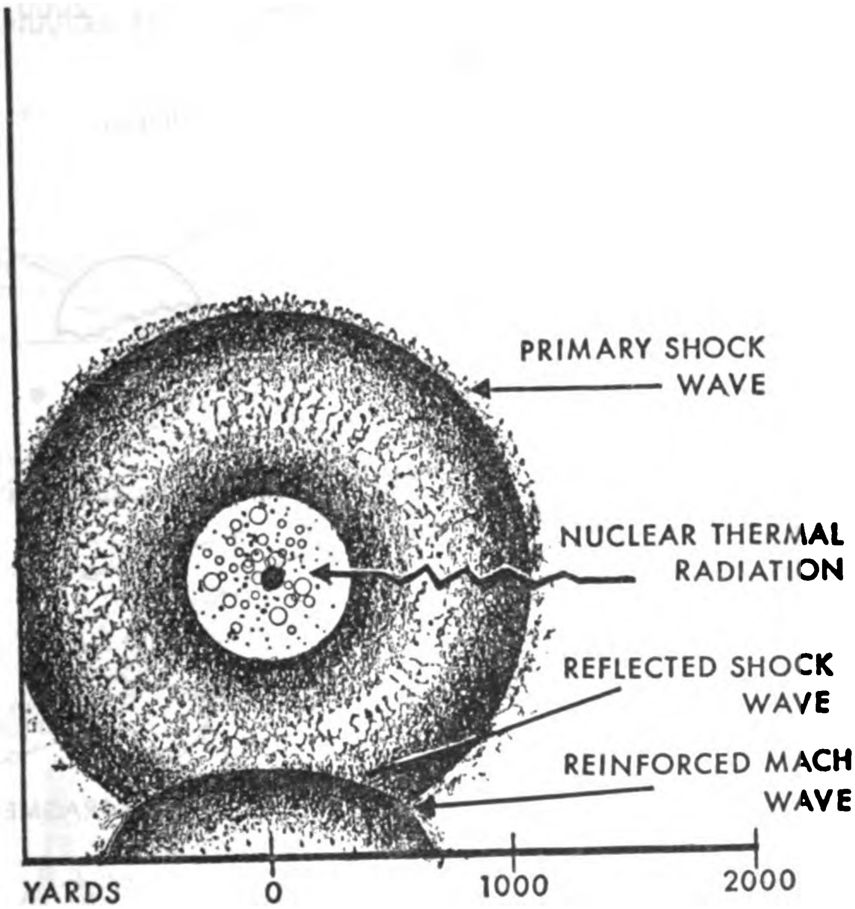

CHART III. Sectional view development of an atomic air burst.

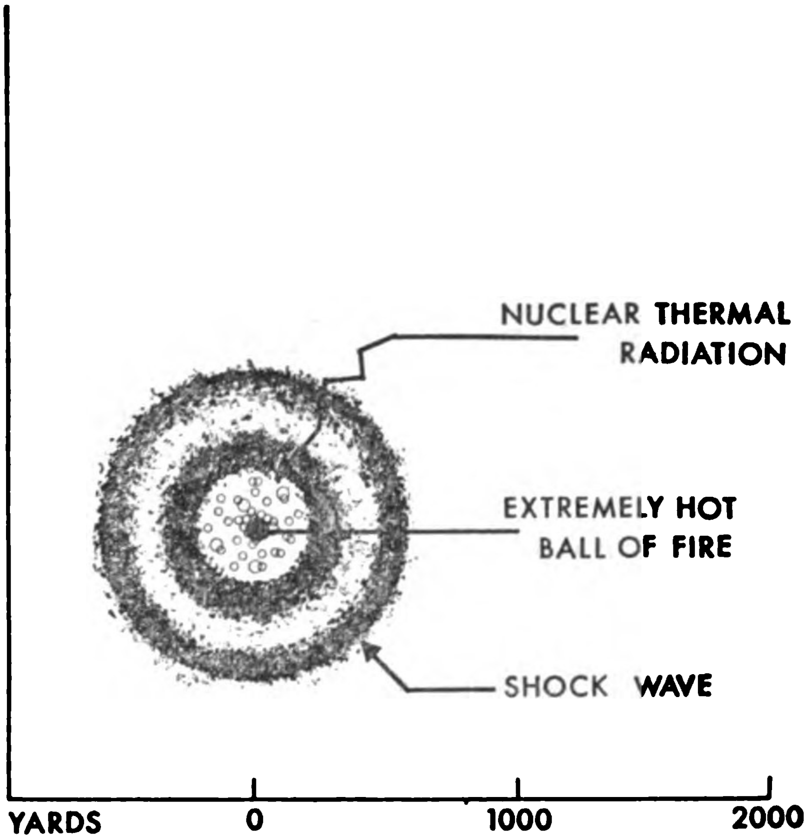

Chart IV

Sectional view development of an atomic burst.

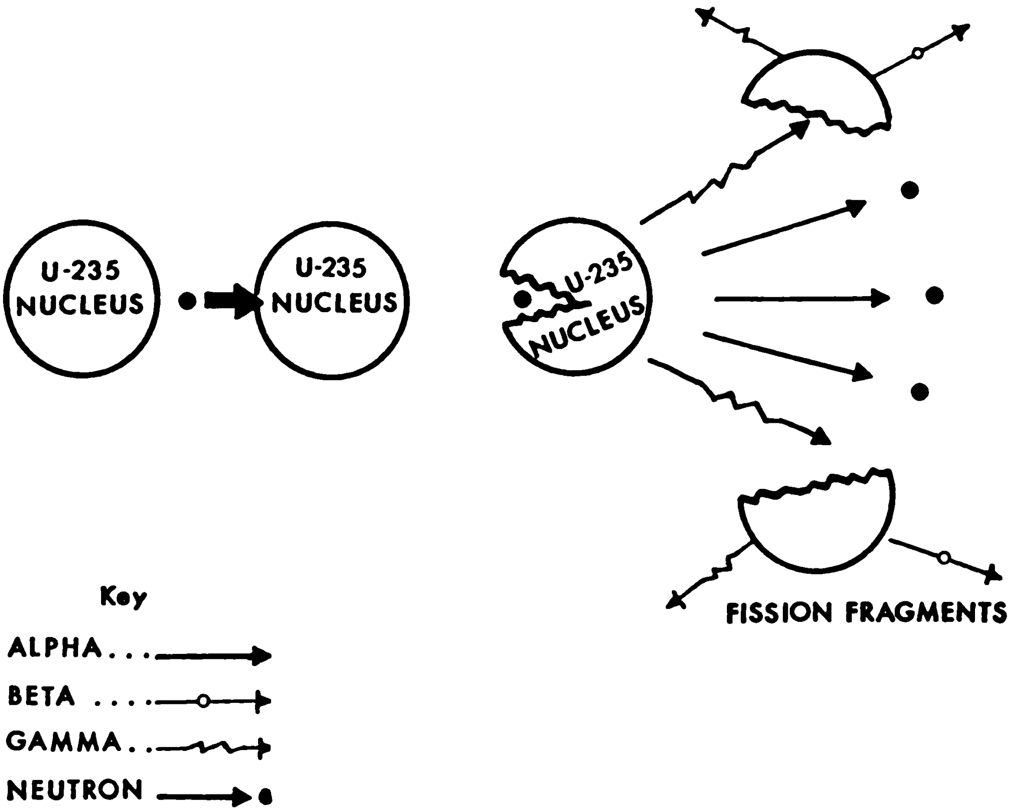

CHART V.—Fissioning of U-235 nucleus.

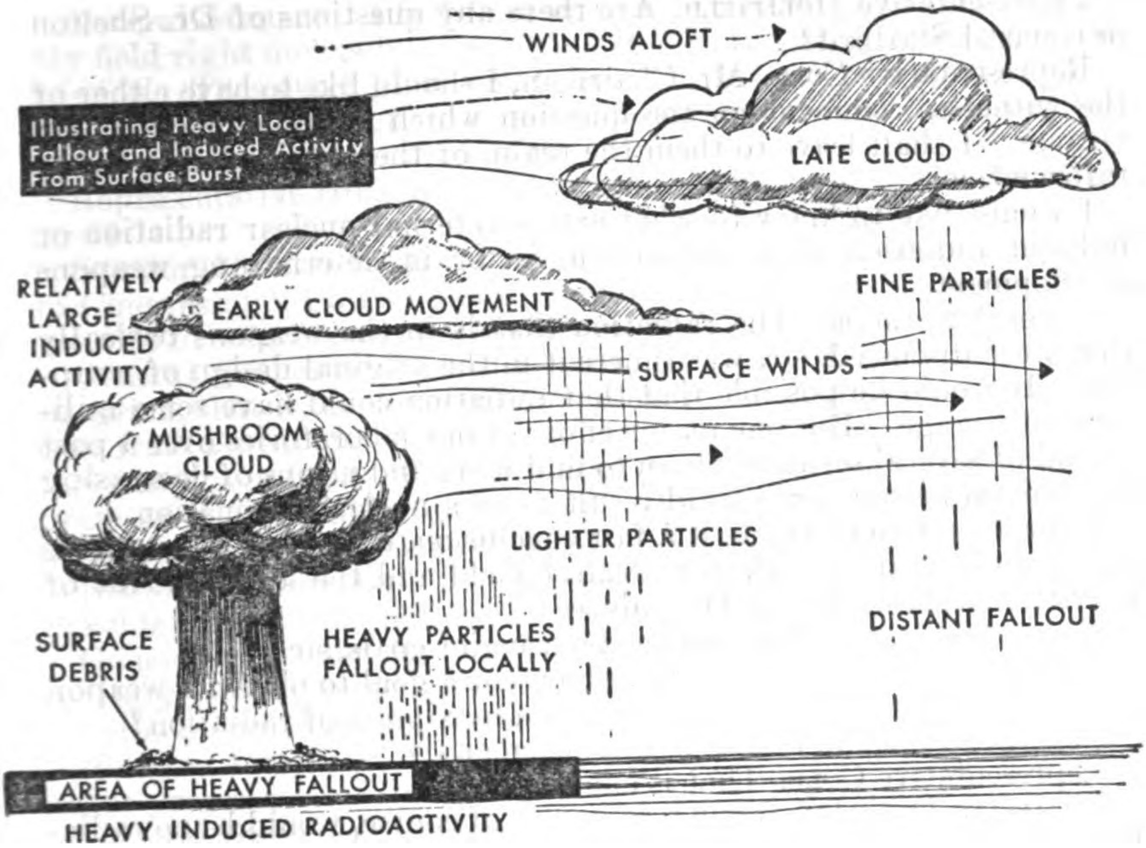

CHART VI.—SURFACE BURST

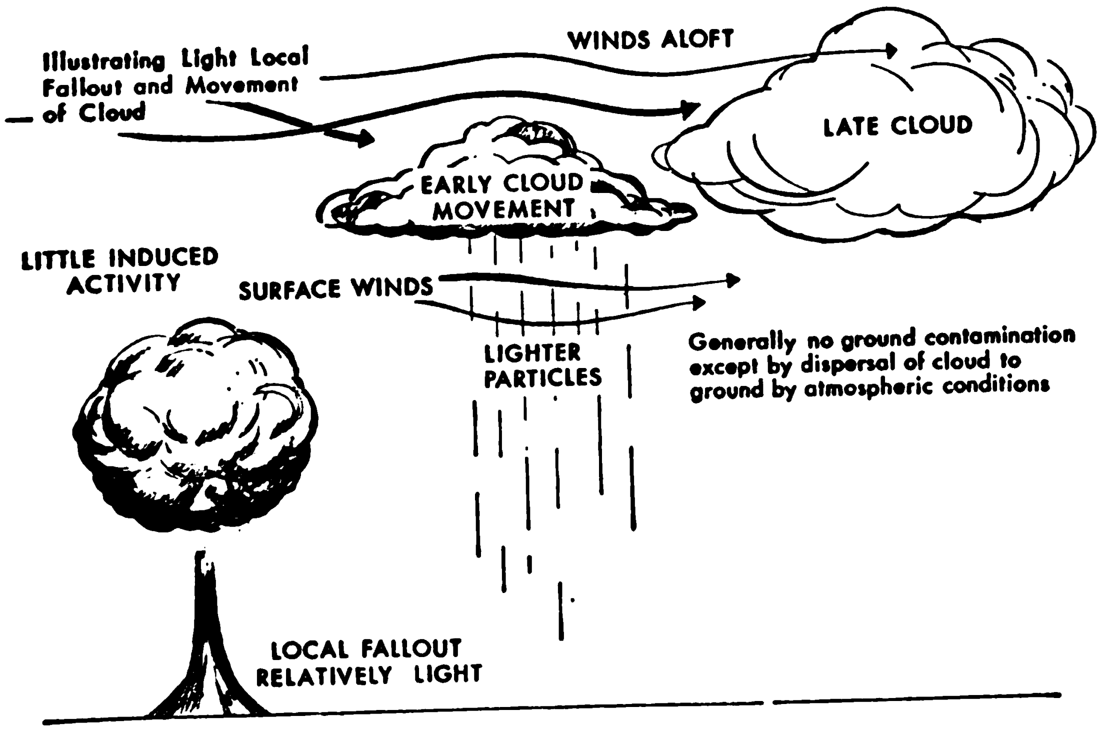

CHART VII.—AIRBURST

Representative HOLIFIELD. Are there any questions of Dr. Shelton or General Starbird?

Representative COLE. Mr. Chairman, I should like to have either of the witnesses comment on the question which I propounded to Dr. Graves. I shall leave to them the realm of the classified or security information.

I would like to know to what extent internal nuclear radiation or induced radiation is an important factor in determining weapons development.

General STARBIRD. The radiation that is in the weapons basically that were discussed, sir, was inherent in the original design of weapons. It would be possible that that radiation could have some military advantage. But our major effort of our laboratories over a past period of several series has been to find ways and means of decreasing the contamination that would result from a nuclear detonation.

Representative COLE. Is it a fair conclusion, then, that your goal is to obtain a weapon with the greatest yield and the least amount of radiation, whether internal or induced?

General STARBIRD. That is one of our major goals, sir.

Representative COLE. Is it to any extent a goal to obtain a weapon with a minimum of blast and heat and a maximum of radiation?

General STARBIRD. I know of no such goal, sir.

Representative COLE. That is enough.

Chairman DURHAM. Your preference, of course, would be no radiation?

Representative COLE. If you can get the same blast.

General STARBIRD. To carry out the objective I mentioned, the fulfillment of that objective would be to get none.

Representative VAN ZANDT. Does a nuclear weapon offer a field commander the capability of contaminating an area with radiation?

General STARBIRD. As Dr. Graves mentioned, a greater amount of radioactivity can be placed locally. I think, sir, this would be the best answer. However, I cannot comment on whether that would be an objective.

Representative VAN ZANDT. Then radiation does play a part in the prosecution of a nuclear war.

General STARBIRD. It certainly plays a part, sir.

Representative HOLIFIELD. As a matter of fact, you cannot have a nuclear war as far as you know now without radiation, can you?

General STARBIRD. I know of no way.

Representative HOLIFIELD. Looking at this strictly from a military standpoint, why would you, without any assurance that the enemy is doing likewise, want to decrease one of the powerful elements of the weapon—there being 3 elements, 1 blast, 1 heat, and 1 radiation—looking at it strictly from a military standpoint. Why would you deny yourself one of those elements?

General STARBIRD. One would like to have weapons that he has the greatest amount of control over.

Representative HOLIFIELD. But if you did have a weapon where you had a maximum control over the factor of radioactivity would you have any assurance that a ruthless enemy would not take advantage of this other powerful element of the weapon in an onslaught against us?

General STARBIRD. I feel I am not really the one to answer that, sir. My field right now is in an assignment with the Atomic Energy Commission. To answer your point from a personal viewpoint, I don't know of anything that we could do to guarantee that the other man would do likewise.

Representative HOLIFIELD. Are there any questions of General Starbird?

Senator ANDERSON. Did I understand you a moment ago in answer to Congressman Cole's question to say that you were trying as far as possible to reduce the radiation in weapons?

General STARBIRD. This is an objective, sir, of the Commission's program, that is, to find ways and means of reducing the contamination from a weapon.

Senator ANDERSON. I am not talking about the Commission's program now. I am talking about the military program. Do I understand it to be your testimony that the military is now engaged in trying to reduce the radiation? If so, I would like to whisper to you here on the side the question that you can either comment on or not.

General STARBIRD. No, sir, I think I can comment. Certainly the military has indicated to us a great interest in weapons that have a lesser contamination for the yield involved.

Senator ANDERSON. I was not talking about interest. I was talking about program.

General STARBIRD. We are the ones, sir, as you know, who actually do the development work and the actual research for the production of the nuclear weapons. Generally to carry out an express requirement or expression of interest by the Department of Defense.

Senator ANDERSON. To whom can I direct a final question and see if it is classified?

General STARBIRD. Mr. Marshall is Director of Classification.

Representative VAN ZANDT. General, is it not true that in the employment of special weapons the field commander has to have a variety of them? He may call upon a weapon where he wants no contamination left after the burst, or he may employ a weapon where he wants to contaminate a great area. So it is up to you people to develop various types of weapons to give him the versatility he must have in the prosecution of a nuclear-type war. Am I correct in that assumption?

General STARBIRD. It is true that a versatility of weapons increases the strength of the military force, sir.

Senator ANDERSON. I have no further questions.

Representative HOLIFIELD. Thank you very much, gentlemen. As I said to Dr. Shelton, we will want to look at this book and possibly call you back later.

General STARBIRD. Thank you, sir.

Representative COLE. Would the Chair indulge me for just a moment in order that I may fill in a gap—not from these witnesses—when Dr. Graves said at the motel in Nevada the highest dosage was 7 point something roentgens.

Dr. GRAVES. That is correct.

Representative COLE. Tell us, since you are here, Doctor, what are the rules of the Commission with respect to safe dosages of workers in the Commission's laboratories, and so forth.

Dr. GRAVES. I have forgotten the title, but I think it is the American Commission for Radiation Protection, or something of that sort, originally stated that the workers in radioactivity could take one tenth of a roentgen per day forever without suffering injury. In the Commission laboratories it was determined that we should reduce that by roughly a factor of two and so it has been reduced to three-tenths of a roentgen per week.

In our test operations we have said that we will permit our people to take this three-tenths of a roentgen per week. However, they went for a quarter of a year, which would be 13 weeks, and hence our test criterion has been something like 3.9 roentgens per quarter or per period of 13 weeks. This means that our people in the test series we have tried to keep below 3.9 roentgens. We have not always done that. As a matter of fact, there have been a number of cases where people have gotten 3, or 4, or 5 times that much. For people offsite, we would like to do better than that. It is our feeling that if people are not willingly engaged in this activity, we should not ask them to take as much as we do. So we try to say that people offsite should not get more than 3.9 roentgens per year instead of per quarter. The present criterion is, I guess, 3.9 roentgens per series.

Representative COLE. I would like you to comment on the lethality of the 7 or so roentgens given to the motel.

Dr. GRAVES. The lethal dose is around 450 roentgens. This is very much less than that. Again this is not a subject on which I am an expert. So I don't want this to be taken as expert testimony in your record. To my knowledge, in order to be able to examine the blood or tissue or blood of someone and find out they have been exposed to radiation, the minimum dosage you can detect by some changes in the body you can see immediately is something like 20 or 25 roentgens. If it is less than 20 or 25 roentgens, there is no test we can make on an individual to show he has had radiation. If we get up above 20 or 25 roentgens, you begin to notice that there have been changes made in the blood. Some cells have become broken up or deformed in one way or another. You can detect some small changes above 25 roentgens. At about 75 roentgens or 100 roentgens a person would become ill, nauseated, and have some radiation sickness, and would recover, and presumably be all right. It is around 400 roentgens when you begin to find a few people die. Around 450 about half of the people would die, or something of that sort. So this 7 roentgens is considerably less than the amount that one can detect by any means that we know of for detecting radiation.

Representative COLE. Is it a fair conclusion, then, that the persons who may have been exposed to that dosage of 7 roentgens were not harmed in any way.

Dr. GRAVES. That is not a fair statement, because then you get me in trouble with people who are worried about long-term effects.

Representative HOLIFIELD. The Chair might say we are going into the pathology feature of this, and we have a list of distinguished witnesses that will testify on this point.

Dr. GRAVES. Yes. I want to be sure you understand I am not an expert in this field. I do not mind talking about it, but do not take my testimony as expert in that particular connection.

Representative VAN ZANDT. Mr. Chairman, may I ask this question. Doctor, how many roentgens did your body absorb in the Los Alamos accident?

Dr. GRAVES. I had about 200.

Representative COLE. From outward appearances you look rather healthy.

Dr. GRAVES. Thank you.

Representative COLE. At this time some several years later.

Dr. GRAVES. That was in 1946, so it has been 11 years. But this really is not important. You may have one person take 200 roentgens as I did and be perfectly happy for 10 years. But does it give me a greater probability of having cancer or does it give me a greater probability of this, that or the other, we just do not know. The danger is not that this will happen to you. The danger is that it is more likely to happen to you. Maybe the more likely is not very much more likely, but it is still more likely.

Representative VAN ZANDT. Doctor, how did this dose of radiation affect you?

Dr. GRAVES. I was nauseated for the first day. I was in the hospital for 2 weeks. I never did feel very sick but I was quite—I did not have very much ambition, I was tired, I got tired climbing steps and so on, and this lasted for perhaps 6 months. At the end of 6 months I was back to work, and I can't tell any difference now.

Representative VAN ZANDT. Did it affect your hair in any way?

Dr. GRAVES. I lost the hair on one side of my head. I did not have to shave for a while, which was a byproduct that was useful.

Representative VAN ZANDT. How about your eye?

Dr. GRAVES. I have a radiation cataract in one eye. The other eye is perfectly all right.

Representative HOLIFIELD. What was the white corpuscle count at the end of 6 months?

Dr. GRAVES. At the end of 6 months it was back to normal. You can't tell anything. You can examine me with a microscope or anything else, and you can't tell any difference now. At the time my white blood count dropped from about 8,000 or 9,000, which was normal, down to around 2,000. Again I don't have these numbers in front of me, so I don't remember exactly. But at the end of perhaps a week or 10 days the count began to increase again, and got back to normal. As a matter of fact, it got above normal. By 6 months it was back to normal, and stayed there ever since.

Representative HOLIFIELD. Dr. Graves, I think I express the feelings of every member of this committee that have known about this for so many years, that we are glad you are in as good health as you are today, and we want to again express our thanks to you for the tremendous contribution you have made to the security of our Nation.

Representative COLE. Mr. Chairman, I just want to concur in what you have said with respect to the attitude of the committee toward Dr. Graves' work. But since we have engaged in some rather personal questions of him with respect to consequences of his exposure, I would like to inquire if since that occurred you have increased your family in any way, and if so, whether the progeny is apparently normal and health. Mr. Chairman, I do not ask it facetiously. Here is a man

who has been exposed to a degree of radiation probably greater than any person that we know. He has told us the consequences to him of his own body. Since radiation exposure has been said to involve a question of sterility and so forth, unless he would rather not answer, I would like to give him the opportunity of indicating.

Dr. GRAVES. I had one daughter before the accident. I have had a daughter and son since the accident. The daughter and son as far as can be told are perfectly normal kids. We love them very much.

Representative VAN ZANDT. From a heredity standpoint, do they show any extraordinary amount of energy as a result of your brush with atomic energy?

Dr. GRAVES. Speaking as a parent they are very intelligent children.

Representative HOLIFIELD. Thank you very much. Our next witness is Dr. W. W. Kellogg of the Rand Corp. and he will speak to us on the subject of atmospheric transport, storage, and removal of particulate radioactivity.

Dr. Kellogg, how long is your presentation?

STATEMENT OF DR. W. W. KELLOGG, RAND CORP.[*]

Dr. KELLOGG. I have a report for the record which is somewhat long, and I was not planning to give it all now. It has a lot of documentation in it. I was going to abstract it to the committee orally. I could do it in 30 or 40 minutes. Is it too late to do that?

Representative HOLIFIELD. We will accept your prepared statement for the record. We will be glad to have you summarize it.

(The statement referred to follows:)

ATMOSPHERIC TRANSPORT AND CLOSE-IN FALLOUT OF RADIOACTIVE DEBRIS FROM ATOMIC EXPLOSIONS

(By Dr. William W. Kellogg, RAND Corporation)

INTRODUCTION

It is well known that the radioactive debris from an atomic explosion is carried high into the atmosphere, and that eventually all of it reaches the ground. However, there are a variety of things which can happen to these particles on their way to ground, and their paths can be quite complicated. The purpose of the present report is to describe and document part of this process of radioactive fallout.

In order to limit the discussion, fallout here will be taken to mean "close-in fallout," the fallout which occurs during the first day or two following the explosion, and which deposits radioactivity within a few hundred miles of ground

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[*] Born: February 14, 1917, at New York Mills, N. Y. Educated: Brooks School, North Andover, Mass.; Yale University, bachelor of arts, 1939; University of California, Berkeley, graduate studies in physics; UCLA, master of arts in meteorology, 1942; UCLA, doctor of philosophy in meteorology, 1949. Occupations: Prep school science teacher (Brooks), 1939–40; teaching assistant, physics, University of California, 1940–41; U. S. Air Force, pilot weather officer, separated with rank of captain, 1941–46; research assistant, research associate, and assistant professor (in succession), Institute of Geophysics, UCLA, 1946–52; research scientist, the Rand Corp., Santa Monica, 1947–present. Affiliations: American Meteorological Society (committee on admissions, upper atomsphere committee); American Geophysical Union (upper atmosphere committee); Society of Sigma Xi; member, meteorological committee on the biological effects of atomic radiation, National Academy of Sciences-National Research Council; member, working group in internal instrumentation of the earth satelite program; member, ad hoc panel for measuring radioactivity in air of the United States National Committee for the International Geophysical Year; formerly member, upper atmosphere committee, NACA (now defunct). (Submitted by Witness.)

zero. The intermediate scale of fallout (that which occurs in the first few weeks) and the worldwide fallout will be treated by others.

Although the purpose is to tell what we know about fallout, an effort will also be made to point out the areas of uncertainty in our knowledge. Fallout is a process which is affected by many different things, and the atmosphere by its very nature behaves in an erratic and random way. Thus, it is fair to say at the outset that, no matter how well we could document our observations of fallout, there would still be an area of uncertainty due to the randomness of the process. This aspect should be borne in mind in considering the evidence which follows.

DESCRIPTION OF THE PROCESS OF CLOSE-IN FALLOUT

There is a fundamental difference between the fallout from an atomic device detonated at the ground and the fallout from one detonated so high that the fireball does not touch the ground. In the case of the surface burst, large quantities of surface material are broken up, melted, and even vaporized, and some of this material comes in intimate contact with the radioactive fission products. Then, after the atomic cloud has stopped rising and the violent updrafts associated with the explosion have subsided, the larger and heavier particles start falling back to the ground. The result is an area around ground zero and extending downwind which is covered in a more or less systematic way with particles contaminated by atomic debris.

In the case of an air burst in which the white-hot fireball never reaches the surface, the radioactive fission products never come into close contact with the surface material; they remain as an exceedingly fine aerosol. At first sight this might be thought to be an oversimplification, since there have been many cases in which the fireball never touched the ground, but the surface material was observed to have been sucked up into the rising atomic cloud. Actually, however, in such cases a survey of the area has shown that there has been a negligible amount of radioactive fallout on the ground. Though tons of sand and dust may have been raised by the explosion, they apparently did not become contaminated by fission products.

The explanation for this curious fact prabably lies in a detailed consideration of the way in which the surface material is sucked up into the fireball of an air burst. Within a few seconds from burst time, the circulation in the atomic fireball develops a toroidal form, with an updraft in the middle and downdraft around the outside. Most of the fission products are then confined to a dough-nut-shaped region, and may be thought of as constituting a smoke ring. When the surface debris is carried into the fireball a few seconds after the detonation, it passes up along the axis of the cloud, through the middle, and can often be seen to cascade back down around the outside of the cloud. In its passage through the cloud, it has passed around the radioactive smoke ring but has never mixed with it.[1]

There has not been a large number of surface shots in the United States test series, and most of these have been set off in the Pacific area, where complete documentation of the fallout has been difficult because the greater part of the material came down in the open ocean or in the water of the lagoons. During the last Pacific test, however, a method of surveying the ocean to determine the distribution of the fallout was used which has given us some fairly complete and quantitative data on the pattern of the fallout from some larger yield devices.[2] A reanalysis of the fraction of the debris which came down within the first few hundred miles from the various Operation Redwing surface shots by Tucker,[3] based on the ocean and atoll survey made jointly by the Scripps Institute of Oceanography, the Naval Radiological Defense Laboratory, the Evans Signal Laboratory, the New York Operations Office of the AEC, the Chemical Warfare Laboratories of the Army Chemical Center, and the Air Forces Special Weapons Center, reveals that from a large yield surface burst about 85 percent falls down in roughly the first 24 hours; for a barge shot in the water of a lagoon the fraction is between 65 and 70 percent. According to Tucker, the accuracy of the estimates

[1] Kellogg, W. W., R. R. Rapp, and S. M. Greenfield: Close-In Fallout, Jour. Met., vol. 14, No. 1, pp. 1–8, 1957.
[2] Van Lint, V. A. J., L. E. Killion, J. A. Chiment, and D. C. Campbell: Fallout Studies During Operation Redwing, Field Command, AFSWP, Operation Redwing Preliminary Report, ITR–1354, October 1956 (Secret, R. D.).
[3] Tucker, B. L.: Fraction of Redwing Radioactivity in Local Fallout, RAND Corp., Report in preparation, May 1957 (Secret, R. D.).

here is probably no better than 20 or 30 percent, so the good agreement which he obtained for various kinds of shots may be fortuitous.[4]

The one other piece of evidence on the fraction falling out from a surface shot comes from Operation Jangle. The Los Alamos Health and Safety Division had a number of stations downwind to record the fallout, and the Air Force surveyed a larger area by flying an instrumented aircraft at low altitudes over the desert. Two analyses have been made of the resulting fallout pattern in order to estimate the fraction of the debris which was represented, one by Lulejian[5] and the other by Rapp.[6] The results are as follows:

	Percent
Lulejian: Beyond 10 miles from ground zero and within 200 miles	60±20
Rapp: Beyond 4 miles from ground zero and within 200 miles	77
Rapp: Total fallout out to 200 miles	87

It should be noted that the famous March 1, 1954, test of the Castle series in the Pacific, which received some publicity because of the fallout on some nearby inhabited atolls,[7] was not well enough documented to enable one to get a good estimate of the percentage of fallout. In order for such an estimate to be made it is clearly necessary to be able to lay out the *complete* fallout pattern. This was not possible here, since the islands on which the fallout occurred occupied only a part of the pattern, and were probably not in the region of maximum fallout. This event will be discussed more below.

As pointed out above, if the height of burst is raised, the amount of surface material which can become intimately mixed with the fission products becomes less. As a result, the fraction which takes part in close-in fallout decreases with increasing height of burst. A tower shot does not exactly follow this trend, however, since the material in the tower itself and in the cab at the top of the tower apparently provides some radioactive fallout. The fraction falling out from a tower shot appears to be quite variable, as can be seen from the following tabulation prepared by Kenneth Nagler and Dr. Lester Machta of the United States Weather Bureau, based on a detailed analysis of the actual fallout from a number of tests in Nevada, all of which had yields in the range of 12 to 18 kt.

	Percent
300-foot tower	17.8
	12.3
	8.9
	7.8
	7.0
Average	10.8
500-foot tower	5.4
524-foot airburst (especially uncertain)	1.0

It should be noted that the particular airburst cited here produced a fireball which almost touched the ground. Higher airbursts, as mentioned above, produce no significant close-in fallout.

So far the discussion has been concerned with the *total amount* of radioactive material taking part in the fallout. The *distribution* of this material on the ground depends on a number of parameters—wind structure, yield and height of burst, and kind of surface. The yield and height of burst predominantly determine the distribution of radioactivity with size of particle, and the height and size of the cloud at time of stabilization. The kind of soil taken into the fireball presumably has an effect on the particle size distribution too. In order to make a calculation of where the debris will go, all these factors must be taken into account in one way or another. The various ways of handling this complicated situation are treated in the next section.

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[4] In ref. 2, Appendix E, similar estimates are made which are less than the ones quoted. However, it appears that a different "normalization factor" was used to convert from kt yield to megacurries of fission product activity at one hour, and this was combined with an inappropriate decay rate to convert from the time of observation to the reference time of 1 hour. Further, Tucked introduced a correction for the radioactive sodium from the ocean water which was activated by neutrons from the explosion, and which contributed to the observed radioactivity.

[5] Lulejian, N. M.: Radioactive Fallout from Atomic Bombs, Air Research and Development Command, C3–36417 (with supplement), November 1953 (Secret, R. D.).

[6] Greenfield, S. M., W. W. Kellogg, F. J. Krieger, and R. R. Rapp: Transport and Early Deposition of Radioactive Debris from Atomic Explosions, Report of Project Aureole, Rand Corp., R–265 AEC, July 1954 (Secret, R. D.). See chapter 4.

[7] Cronkite, E. P., V. P. Bond, and C. L. Dunham: Some Effects of Ionizing Radiation on Human Beings, United States Atomic Energy Commission, July 1956.

Before proceeding further it might be well to mention something about what happens to these radioactive particles after they are on the ground. The largest particles involved may be a millimeter or more in diameter, but these constitute only a small fraction of the total debris. Both observation of the particles, collected in many ways in the Pacific and in Nevada, and theoretical calculations of the way in which they must fall indicated that the majority of the particles taking part in the close-in fallout have diameters between about 50 and 400 microns (1 micron is 10,000 cm.).[8 9 10 11] According to G. R. Hilst, of the Hanford Atomic Products Operation, particles of less and about 50 microns diameter are difficult to erode by wind action because they tend to sift down and cling between the larger particles of the soil, and particles larger than about 500 microns diameter are difficult to erode because the wind cannot easily lift them. The particle size range in which radioactive fallout lies is the size which can be most easily lifted by the wind and redeposited somewhere else. Under high wind conditions this could further complicate the prediction of where the debris would go.

COMPUTING FALLOUT PATTERNS

Clearly, the direction that a particle takes on its way to the ground is determined by the wind. It is not the wind at one level alone which must be considered, but the cumulative effect of all the winds between the ground and the initial altitude of the particle. There have been a number of mehods developed to make some sort of best guess about where the debris will be deposited, and these all have one element in common: The wind field from the ground up to the atomic cloud must be analyzed and integrated.

In order to understand the matter of fallout computation, it is necessary to see what is involved in an integration of the wind field. Figure 1 shows, in schematic form, how such an integration can be done vectorially. Let it be assumed for the moment that a particle starting from 50,000 feet, for example, has a constant rate of fall. In such a case it will spend the same amount of time in each layer of a given thickness, say 5,000 feet. The direction of its travel while in a given layer will be in the direction of the mean wind in that layer, and the distance it travels while in the layer will be proportional to the length of the corresponding wind vector. Then it falls down into the next layer and again travels with the mean wind in that layer. In order to determine the total distance and direction which this particle traveled on the way to the ground it is only necessary to add the successive wind vectors for each layer head to tail, and the resultant vector will represent the total travel.

In practice, meteorologists have found it convenient to add the vectors starting from the ground and working upward, as shown in figure 1b. Now the integrated wind, or total particle travel, from any given altitude can be immediately determined by drawing a vector from the origin to the head of the arrow corresponding to the correct altitude. In other words, a family of integrated winds can be produced in this way, and the direction and rate of travel of all particles can be estimated by inspection of the diagram. Recall that it was assumed here that the particles fell at a constant rate. This is not the case in actuality, and so the simple vector addition described here must be modified in the more sophisticated analyses of fallout.

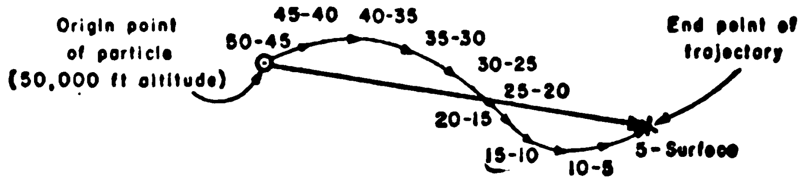
There have been four main approaches to the construction of a fallout analysis, depending on the amount of time available for the computation and the degree of completeness required. It should be emphasized that these various approaches do not compete with each other, since they are each tailored to answer a different set of questions about the fallout, and they differ greatly in the amount of labor required to carry them out. In order of increasing complexity, they are—

[8] Rainey, C. T., J. W. Neel, H. M. Mork, and Kermit H. Larson: Distribution and Characteristics of Fall-Out at Distances Greater than 10 Miles from Ground Zero, March and April 1953, U. C. L. A. School of Medicine, Operation Upshot-Knothole, WT-811, February 1954 (Secret. R. D.).

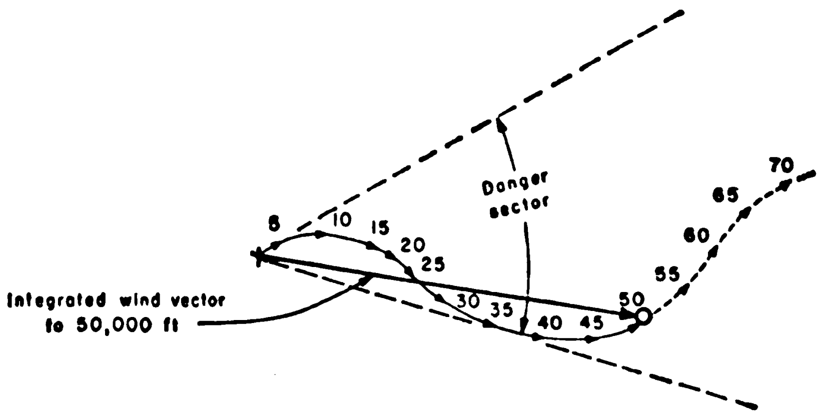
[9] Heldt, W. B., Jr., E. A. Schuert, W. W. Perkins, and R. L. Stetson: Nature, Intensity, and Distribution of Fallout from Mike Shot, U. S. Naval Radiological Defense Lab., Operation Ivy, WT-615, November 1952 (Secret, R. D.).

[10] Stetson, R. L., E. A. Schuert, W. W. Perkins, T. H. Shirasawa, and H. K. Chan: Distribution and Intensity of Fallout, U. S. Naval Radiological Defense Lab., Opertaion Castle, WT-915, January 1956 (Secret, R. D.).

[11] Wilsey, E. F., R. J. French, and H. I. West, Jr.: Fallout Studies, Army Chemical Center, Operation Castle, WT-916, February 1956 (Secret, R. D.).



(a) Actual particle trajectory



(b) Usual method of plotting and integrating the wind field

FIGURE 1.—Schematic representation of a wind field and the analysis of a falling particle's trajectory.

1. *The danger sector.*—An inspection of the integrated wind plot shown in figure 1b shows that all the particles starting in a vertical line over the origin would travel within the sector indicated by the dashed lines. This can be called the danger sector, since it is the sector within which the debris will fall, more or less, assuming a perfectly constant wind field. Certain refinements can be made to the simple sector presentation with little effort, such as delineation of the times at which the particles starting over ground zero will reach a given point on the ground; and the finite initial size of the atomic cloud can be taken into account graphically. This approach has been described in detail in several readily available reports.[12 13 14] Since it is quick and convenient, it is the method which has been recommended by the Weather Bureau, the Air Weather Service, and the FCDA for use in weather stations in an emergency. In order to further expedite the computation, the Weather Bureau has recently instituted the inclusion of the integrated winds from each upper wind station in the routine teletype message. These go by the code name of "UF winds," and are available from about 70 weather stations within the United States twice daily. Note, however, that the danger sector method does not provide a way for telling the actual levels of activity and does not distinguish the parts of the sector which are more intensely contaminated, though there are some methods for roughly estimating where these will be.

2. *The idealized pattern.*—Several of the earlier workers in the field of fallout noted the fact that the majority of the patterns (in Nevada) had a characteristic cigar shape.[5 15] It was therefore tempting to attempt to characterize fallout patterns in general in terms of a family of simple elliptical shapes, with a circular

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[12] Air Weather Service Manual 105–33, Radioactivity Fall-Out and Radex Plots, Hqs., Air Weather Service, June 2, 1952.

[13] Construction of Fallout Plots from Coded Messages Provided by the U. S. Weather Bureau," Federal Civil Defense Administration, Battle Creek, Advisory Bulletin No. 188, May 25, 1955 (and supplements).

[14] Training Manual for Computing and Coding Civil Defense Fallout Winds, U. S. Weather Bureau, Washington, April 1955.

[15] Laurino, R. K., and I. G. Poppoff: Contamination Patterns at Operation Jangle, U. S. Naval Radiological Defense Laboratory, Rept. 399, April 1953 (Secret, R. D.).

section around ground zero. The Armed Forces special weapons project (AFSWP) and others have, over a period of years, developed rather elaborate sets of scaling and shaping laws, designed to fit these idealized patterns to a wide range of yields and, to a limited extent, wind conditions. These methods are described in detail elsewhere.[16] A recent report of the Air Force Special Weapons Center by Boyd and Baker has summarized and made comparisons of the various methods.[17] They all have the common characteristic that the only input required is the weapon yield (a surface burst is assumed) and some sort of an integrated wind, sometimes called the effective wind. For certain planning purposes these idealized fallout patterns are quite useful, since they give a good idea of the area covered by a given dose contour, and for a simple wind structure the orientation and shape may be quite representative. However, as our experience with actual fallout patterns grows, it becomes clear that the simple wind structure required to lay down a symmetrical pattern like the idealized ones is not necessarily the expected one, particularly in the Tropics or in Nevada in summer. Therefore, for prediction purposes such a method may be of little value; moreover, the way in which it is presented gives an erroneous impression of the accuracy of the plot, since the dose rate contours are actually specified.

3. *Analog method.*—A very common technique in weather forecasting, one which all meteorologists use either subconsciously or consciously, is the use of analogs. Essentially, this means a sorting over of cases which have occurred in the past to find a situation analogous to the current situation, and presuming that the same processes will follow the same course again. There have not been enough surface bursts to build up a good file of analogs, but an artificial set can be calculated, using the sort of detailed calculations to be described in the next section. Such a "catalog" of fallout patterns has already been produced by the Rand Corp.[18] To make use of this collection of analogs, the meteorologist must find a wind field in the catalog which by proper manipulation can be more or less matched to the current wind field, and he can then take advantage of the fact that the resulting fallout pattern has already been computed in great detail. If the yield does not match, then certain scaling laws can be applied to the analog to make it the correct size. Naturally, the same wind field never occurs exactly the same way twice, but the matching can be done quite successfully over a wide range of conditions and yields.

4. *Fallout models.*—In attempts to describe as closely as possible what actually happens in the fallout process, several agencies have developed techniques in which the particles in the initial atomic cloud are traced down to the ground, and in which their combined effect is then calculated for each point in the fallout field. The result is a polt of the expected dose rate at any given point for a given time. In order to perform such an elaborate computation the following factors must all be considered:

Wind field—in some of the computations it is not only possible to consider the variation with height, but the variation with time and space. Under certain conditions, as will be shown, such variations are quite important.

Initial distribution of particles in space—although the size and shape of the atomic cloud can be observed photographically, the distribution of the radioactivity inside the cloud is not well known. Assumptions about this vary from model to model.

Size distribution of the particles—since the larger particles will in general fall faster than the smaller ones, it is necessary to specify how much of the total radioactivity is associated with each range of particle size. Furthermore, the size distribution probably differs in different parts of the cloud, a feature which some of the models attempt to take into account.

Rate of fall—the rate of fall of a particle depends on its size, density, and shape. Thus, the rates of fall of a given size particle at each altitude must be specified in each model.

Turbulent diffusion—in at least one of the models which has been tried the spread of the trajectories due to random turbulence has been taken into

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[16] Capabilities of Atomic Weapons, Armed Forces Special Weapons Project, TM 23–200/OPNAV Instruction 003400. IA/AFL 136–4/NAVMC 1104, Washington, 1955 (Secret, R. D.). (See sec. 13.)

[17] Boyd, R. E., and D. Baker: Comparison of Methods Used in Scaling Residual Contamination Pattern Resulting from Surface Detonations of Nuclear Weapons. Hqs., Air Force Special Weapons Center, Kirtland AFB. AFSWC–TN–56–1, April 1956 (Secret, R. D.).

[18] S. M. Greenfield, R. R. Rapp, and P. A. Walters: A Catalog of Fallout Patterns, Rand Corp., Rept. RM–1676, April 1956.

account. However, most of the models choose to neglect this effect, since it does not appear to be very important for the early deposition.

Each of the computational models must specify all of the above factors, and there have been some rather large differences between the assumptions, due to our lack of very definite information about the true facts of the matter. In addition, different computational techniques are used to analze the model, some using high speed digital computers, some using special electronic or optical analog computers, and some using a graphical "hand" computation.

In January 1955, the Armed Forces Special Weapons Project (AFSWP) organized a symposium on radioactive fallout, and all the various agencies which had studies the question of fallout were invited to apply their respective fallout models to two specified sets of wind conditions, known as condition A and condition B. The results, as published in the AFSWP report on the symposium [19] are shown in figures 2 and 3. The winds used are tabulated in table 1 and table 2. For details of the actual computational schemes used, one should refer to the fallout symposium report [19] or to the reports of the various agencies, some of which have become unclassified.

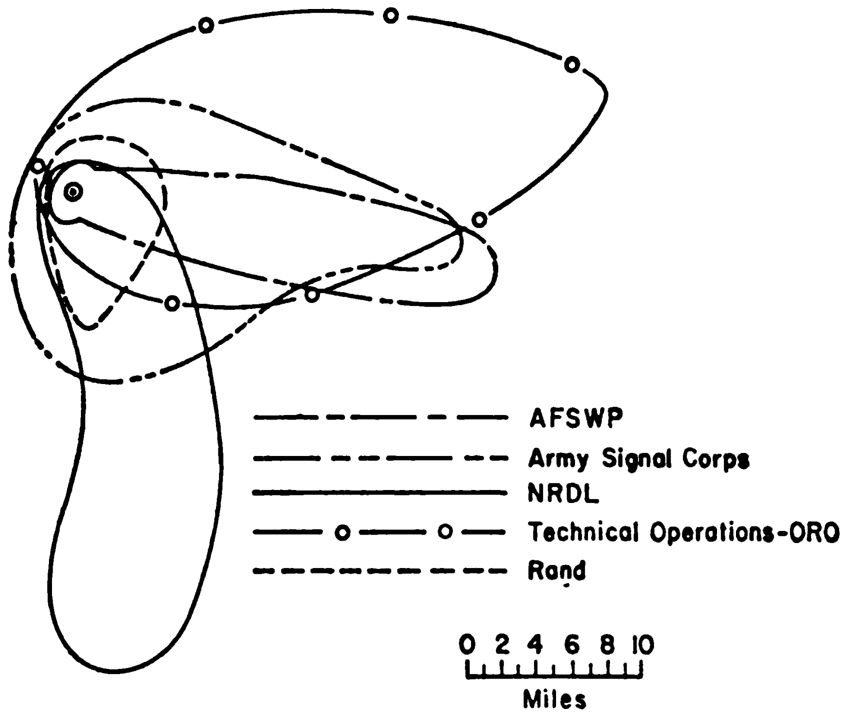

FIGURE 2.—AFSWP comparison of fallout computations (Ref. 18). Cases for "Condition A," 1 megaton yield, showing contours for 1,500 r dose accumulated by 48 hours.

TABLE 1.—*Condition A—Wintertime situation of an abrupt, approximately 90°, shear at a height of approximately 40,000 feet*

[Dodge City, Kans.—37°46′ N. 99°58′ W.—1500 Greenwich meantime—Dec. 28, 1953—Elevation: 2,625 feet]

Height (feet, mean sea level)	Wind direction (degrees)	Wind speed (knots)	Height (feet, mean sea level)	Wind direction (degrees)	Wind speed (knots)
Surface	260	7	45,000	255	43
5,000	247	12	50,000	255	55
10,000	273	19	55,000	260	47
15,000	307	13	60,000	272	54
20,000	008	16	65,000	289	40
25,000	045	41	70,000	285	36
30,000	036	52	75,000	285	38
35,000	357	29	80,000	285	45
40,000	243	47			

[19] Fallout Symposium, Armed Forces Special Weapons Project Report 895, January 1955 (secret, R. D.).

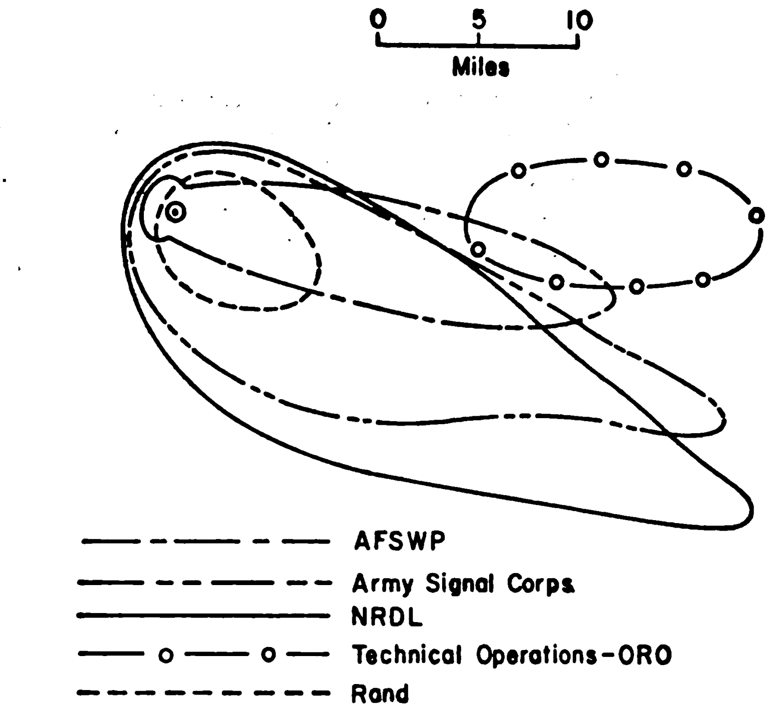

FIGURE 3.—AFSWP comparison of fallout computations (Ref. 18) cases for "Condition B," 1 megaton yield, showing contours for 1,500 r dose accumulated by 48 hours.

TABLE 2.—*Condition B—Gradual shear of approximately 90°*

[Washington, D. C. (Siver Hill)—38°50′ N., 76°57′W.—0300 Grenwich mean time—Sept. 28, 1952—Elevation: 289 feet]

Height (feet, mean sea level)	Wind direction (degrees)	Wind speed (knots)	Height (feet, mean sea level)	Wind direction (degrees)	Wind speed (knots)
Surface	Calm	0	45,000	292	23
5,000	358	11	50,000	290	28
10,000	009	20	55,000	290	20
15,000	325	14	60,000	268	11
20,000	282	19	65,000	276	21
25,000	263	34	70,000	293	7
30,000	263	47	75,000	293	8
35,000	273	37	80,000	285	10
40,000	308	27	85,000	250	11

The significant thing to note is the discouragingly poor agreement between the various results. It is possible that some of the agencies have modified their models in the past 2 years, and that there would be better agreement if the exercise were repeated now, but it is highly unlikely that the agreement would be anywhere nearly exact. It would seem that we simply do not know enough yet about the process of fallout to be able to reconstruct a fallout model (no matter how sophisticated in conception) on which everyone would agree.

PREDICTION AND RECONSTRUCTION OF FALLOUT PATTERNS

As stated in the previous section, there have been a number of methods develeped for the computation of fallout patterns. Naturally, these were developed with the observed fallout from a handful of surface and tower bursts in hand, and all claim (to a greater or lesser degree) to give results which agree with reality.

The real question of agreement with reality is, however, obscured by the fact that reality is hard to define, even in retrospect, when all the facts are collected. First, the wind field is poorly observed, and the variations in the wind field with time and space are difficult to take into account in reconstructing what

happened. The meteorological literature has a number of studies of this variability and of the uncertainties in observation.[20, 21, 22] A good rule of thumb, derived from experience with the tracking of constant-level balloons, is that, over a good upper air network of the sort which covers the United States, the path of a particle cannot be determined from an analysis of the wind field to better than 20 percent of the length of the trajectory. Thus, after going 100 miles, the uncertainty in the position of a drifting particle is about 20 miles, even when we have all the upper-air data which we can lay our hands on.

Furthermore, the fallout itself is poorly observed, due to the great distances that have to be covered, the irregularities of the terrain (in Nevada) or the uncertainty of where it went after landing in the ocean (in the Pacific). Thus, even if our computation were, in principle, a perfect one, we would still not have a clear picture against which to compare it.

When the meteorologist is faced with the problem of *predicting* a fallout pattern, the uncertainties of a wind prediction are added to the uncertainties in the computational model. The longer the time lag between prediction and the event, the greater will be the uncertainties.[23] For times of up to 12 hours, it appears that persistence is about as good as a forecast, and after about 2 to 3 days a forecast is not much better than a climatological mean.

Without belaboring this point, it should suffice to show two interesting examples of predicted and reconstructed fallout patterns. One is from a burst of roughly 30 kilotons on a tower in Nevada, the Open or Civil Defense shot of May 5, 1955. The patterns shown in figures 4 and 5 were prepared by Kenneth Nagler, of the United States Weather Bureau, and show the patterns which were predicted 2 hours before shot time by 2 methods of models. The two models, one of the Weather Bureau and the other of the Los Alamos Scientific Laboratory and the University of California Radiation Laboratory, were used. The first involved a hand computation by an elaborate graphical analysis, the other involved a high speed digital computer (IBM-701). There were some differences in the two models, but these were not basic ones—that is, they both used the general approach described in the previous section. It will be noted that both methods predicted patterns extending due north from the shot point, following the direction of the H-2 hour predicted wind. The observed pattern, shown in figure 6, was reconstructed from the available road monitoring and from a few aircraft measurements by Nagler. The fallout started out northward, and then curved to the eastward, reflecting a gradual shift in the wind direction from south to west that took place in the hours following the shot. Also shown in figure 6 is an attempt to reconstruct the pattern, using the Weather Bureau's model and taking into account the change of wind with time and space. The result agrees with the obesrved pattern better, but still not perfectly.

Another example of a fallout pattern which changed its direction during the later stages of the fallout is the March 1, 1954, Castle shot on the Bikini atoll, referred to earlier. In this case, the fallout apparently started out in a direction east-northeast, but a continued veering of the wind caused it to curve more to the east and east-southeast, until one side of it lay across some neighboring atolls. A study of this event by Rand in which the fallout was computed with the shot-time wind alone, and then again with the variable (true) wind, shows clearly how the pattern must have curved as it progressed.[24]

It is interesting to note that both of these examples demonstrate the effect of the changing wind with time, an effect which is often very hard for the meterologist to specify. A study of the statistics of this change of wind with time has been made by Frank Cuff, department of meteorology, University of Utah.[25] Referring to the integrated wind (see above) from the ground up to various altitudes in Nevada, he found the mean absolute bearing changes shown in table 3.

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[20] Neiburger, N., L. Sherman, W. W. Kellogg, and A. F. Gustafson: On the Computation of Wind from Pressure Data, Jour. Met., vol. 5, No. 3, pp. 87–92, 1948.

[21] Rapp, R. R.: The Effect of Variability and Instrumental Error on Measurements in the Free Atmosphere, New York University Meteorological Papers, vol. 2, No. 1, June 1952.

[22] Kochanski, A. B.: Wind, Temperature, and Their Variabilities to 120,000 Feet, Air Weather Service Technical Report, 105-142, May 1956.

[23] Ellsaesser, H. W.: Errors in Upper-Level Wind Forecasts, Air Weather Service Technical Report, 105–140/1, December 1956.

[24] Greenfield, S. M., and R. R. Rapp: Fallout Computations and Castle-Bravo—A Case Study, Rand Corp., RM–1855, January 1957 (secret, R. D.).

[25] Cuff, R. D.: A Study of the Time Variability of Integrated Winds Near Las Vegas, Nevada, thesis for M. S. Degree, Dept. of Meteorology, Univ. of Utah, March 1957.

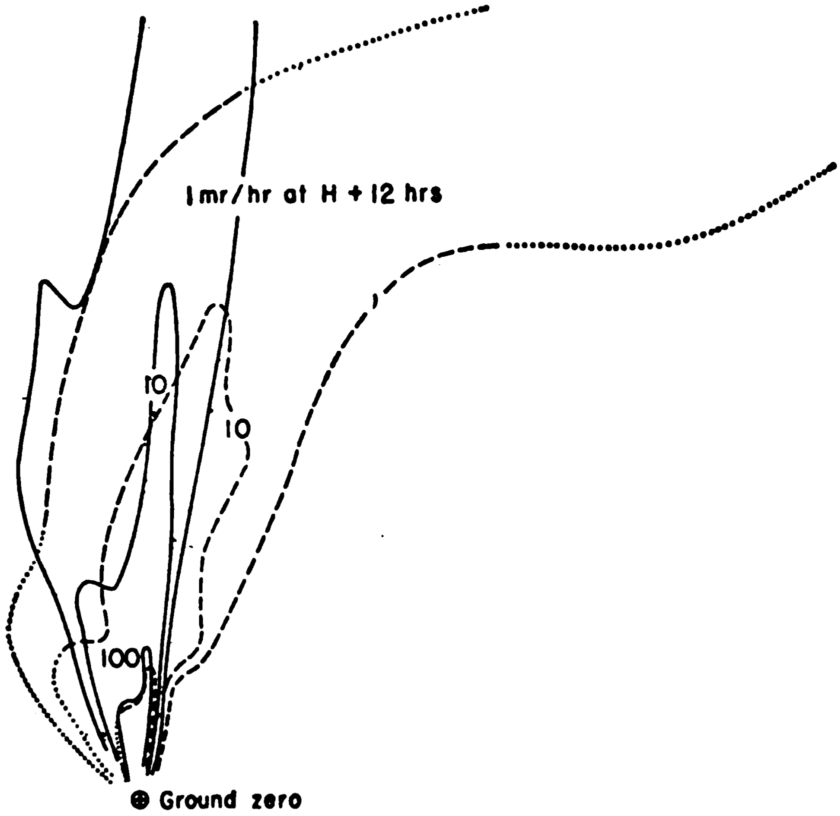

FIGURE 4.—The observed fallout distribution (dashed lines) and the pattern computed by the Weather Bureau using winds predicted at H–2 hours. May 5, 1955.

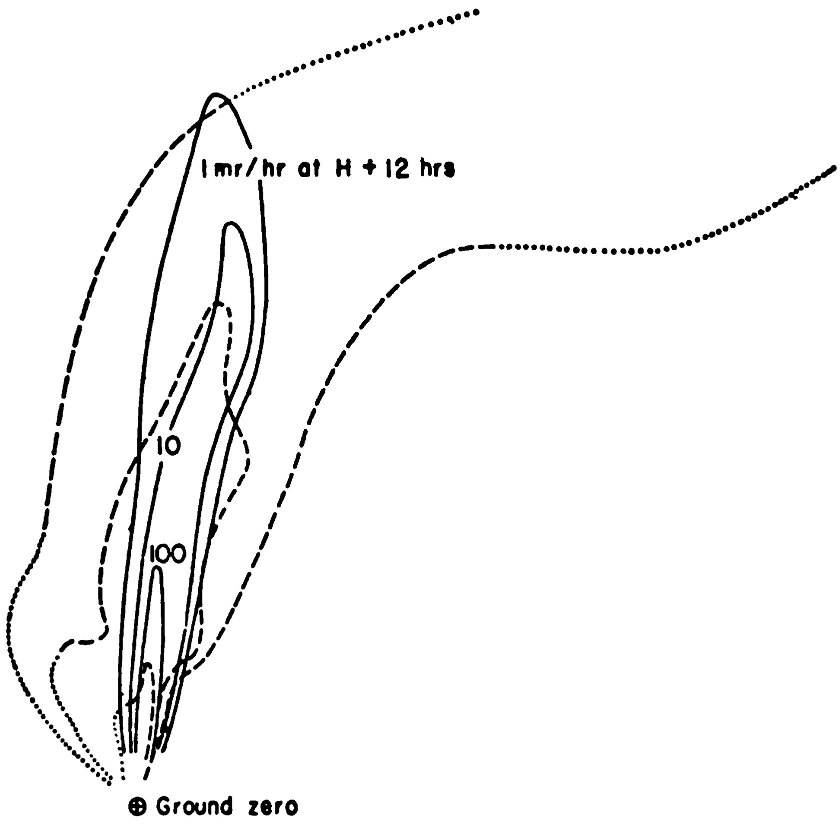

FIGURE 5.—The observed fallout distribution (dashed lines) and the pattern computed by LASL–UCRL using winds predicted at H–2 hours. May 5, 1955.

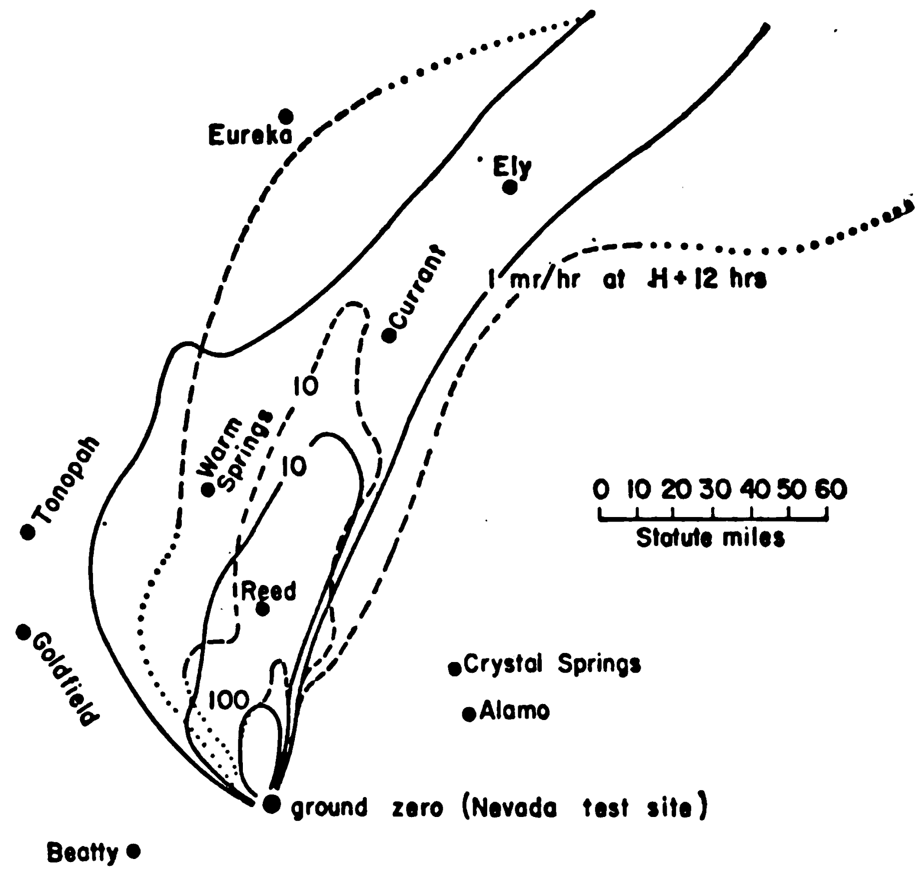

FIGURE 6.—The observed fallout distribution (dashed lines) and the pattern reconstructed by the Weather Bureau using a hand computation with time and space variation of winds (solid lines). May 5, 1955.

TABLE 3.—*Mean absolute bearing change of integrated winds*

Time interval (hours)	Integrated wind from surface to—		
	20,000 feet	40,000 feet	80,000 feet
3	12°	7°	6°
6	22°	15°	13°
12	33°	28°	----------

It will be noted that the bigger the thickness of the atmosphere considered in forming the integrated wind the smaller is the shift of the wind. This probably reflects the fact that wind shifts at one level may sometimes be partially canceled by opposite wind changes at another altitude. Another lesson to be learned from this study is that the statistics of the wind at one level cannot be relied upon to give reliable information about the statistics of the integrated wind, which must combine the effects at many levels.

A recent study of the predictability of fallout for the Nevada test site has been made by Jack Reed of the Sandia Corp.[26] Here the variability of the wind, the forecasting accuracy, the length of the forecast period, etc., are all considered in order to given an estimate of the degree of confidence with which the fallout can be put into an uninhabited "safe sector." This approach to the problem is one which should be taken more often in meteorology, since it demonstrates that any weather forecast should have a prabability assigned to it—a probability which is always less than one.

THE DYNAMICS OF FALLOUT

So far a great deal has been said about the final fallout pattern and how it is computed. A very important feature of the pattern from a practical standpoint

[26] Reed, J. W.: Estimating Safety Probabilities From Fallout Forecasts for Nevada Test Site, Sandi Corp. report SC-4073 (TR), February 1957.

is the *time* at which the fallout reaches various parts of the pattern. Clearly, the fallout cannot all occur at once, since it takes some time for the particles to reach the ground, and while they are falling they are carried with the wind. Thus, the fallout around ground zero starts very quickly, whereas the fallout miles away may not start for hours. (For example, the island of Rongelap did not receive its fallout until some 4 to 6 hours after shot time.[7])

Recall that, for a surface burst of more than a few kilotons yield, most of the radioactive debris is in the mushroom cloud. When the yield is several megatons, this mushroom cloud rises into the stratosphere,[1] and so even the relatively infrequent larger particles, of 1,000 microns diameter and over, take from 30 to 40 minutes to fall back to the ground. It appears that there are some few radioactive particles which escape from the mushroom while it is rising and are left behind in the stem cloud, and these will, of course, find their way to the ground sooner, in the downwind direction.

In order to demonstrate the time of arrival of radioactivity at points relatively close to ground zero, the Naval Radiological Defense Laboratory [9,10] and the Army Chemical Corps [11] have designed equipment which records the fallout as a function of time. Though their respective instruments were designed independently, they both work on essentially the same principle: A small tray or container is uncovered for a certain period of time (say, 5 minutes), then covered again. Automatically the next sampler is uncovered for its sampling period, and so on. It should be mentioned that both sets of instruments remained closed for the first minute after shot time, to allow the shock wave to pass the sampling station.

A large number of such fallout versus time measurements were made at the time of the Castle shot 1, and a few had been made earlier at the Ivy Mike test by NRDL. When all the results using 5-minute sampling times (20 cases) are plotted up one is impressed, first of all, at the erratic nature of the results. This is probably due to the fact that the samples are made with small areas and small time intervals, and therefore do not give results which are entirely representative of the fallout at that location.[27]

The next thing which one notices about the results is that the majority of them show *no fallout for the first 30 minutes;* the average time of arrival for all stations which received any fallout was 28 minutes. These stations were located at distances from ground zero ranging from 8 to 30 miles. In visualizing these distances, recall that the Ivy Mike cloud had a radius of about 5 minutes of 10 miles, and at 10 minutes it was nearly twice this. For the Castle shot 1 the radius at 10 minutes was about 30 miles, and still growing. Thus, all the stations represented were literally in the shadow of the great mushroom cloud—though none were in the initial part of the stem.

The few stations which did apparently receive fallout earlier may have had something wrong with their mechanism (as would appear to be the case where two nearby stations give completely opposite results), or they were in a direction from ground zero which allowed them to be dusted by the material from the crater area which was born by the low level winds. This latter explanation appears to be reasonable, since we know that a certain small fraction of the radioactivity produced does reside in the stem cloud at relatively low altitudes.

It is therefore tempting to visualize the fallout as a slowly descending blanket, with a diameter roughly the diameter of the mushroom cloud. The blanket starts its fall as soon as the atomic cloud stabilizes (about 4 to 6 minutes after burst time) and touches the ground over a large area simultaneously. While this mushroom material undoubtedly represents the major fallout, some material from the stem may reach the ground sooner, and the direction of this immediate fallout from the stem would be determined by the mean wind in the lower levels, below, say, 20,000 feet.

Following this early arrival of the radioactive debris the fallout pattern is laid out in a more or less orderly way and spreads in the direction of the integrated winds. To illustrate how the pattern grows with time, figures 7 and 8 show the growth of a hypothetical 1 megaton pattern under 2 very different wind conditions. One shows how it grows under a condition where the winds are moderately strong and all in the same general direction. The other shows how one grows under a low wind condition. In the first case the debris is spread rapidly in a ribbon across the country. In the second case the debris continues to fall in the vicinity of ground zero for many hours. Neither of these wind conditions is particularly unusual, and there are naturally an infinte number of possible intermediate cases.

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[27] See ref. 10.

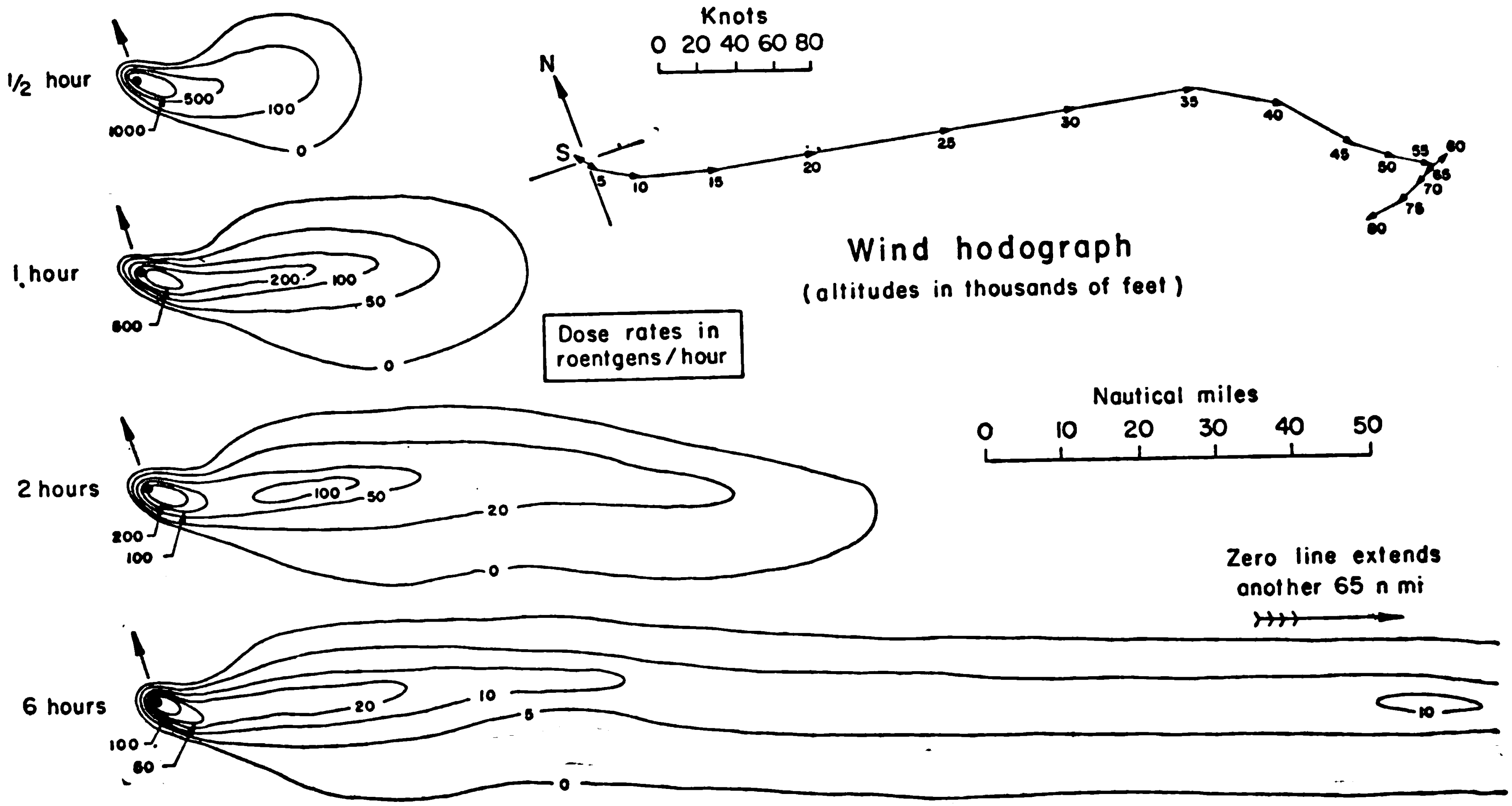

FIGURE 7.—Calculated fallout from a 1 MT surface burst with a two-thirds fission yield under a "high wind" condition. Winds are those for San Francisco on June 15, 1954.

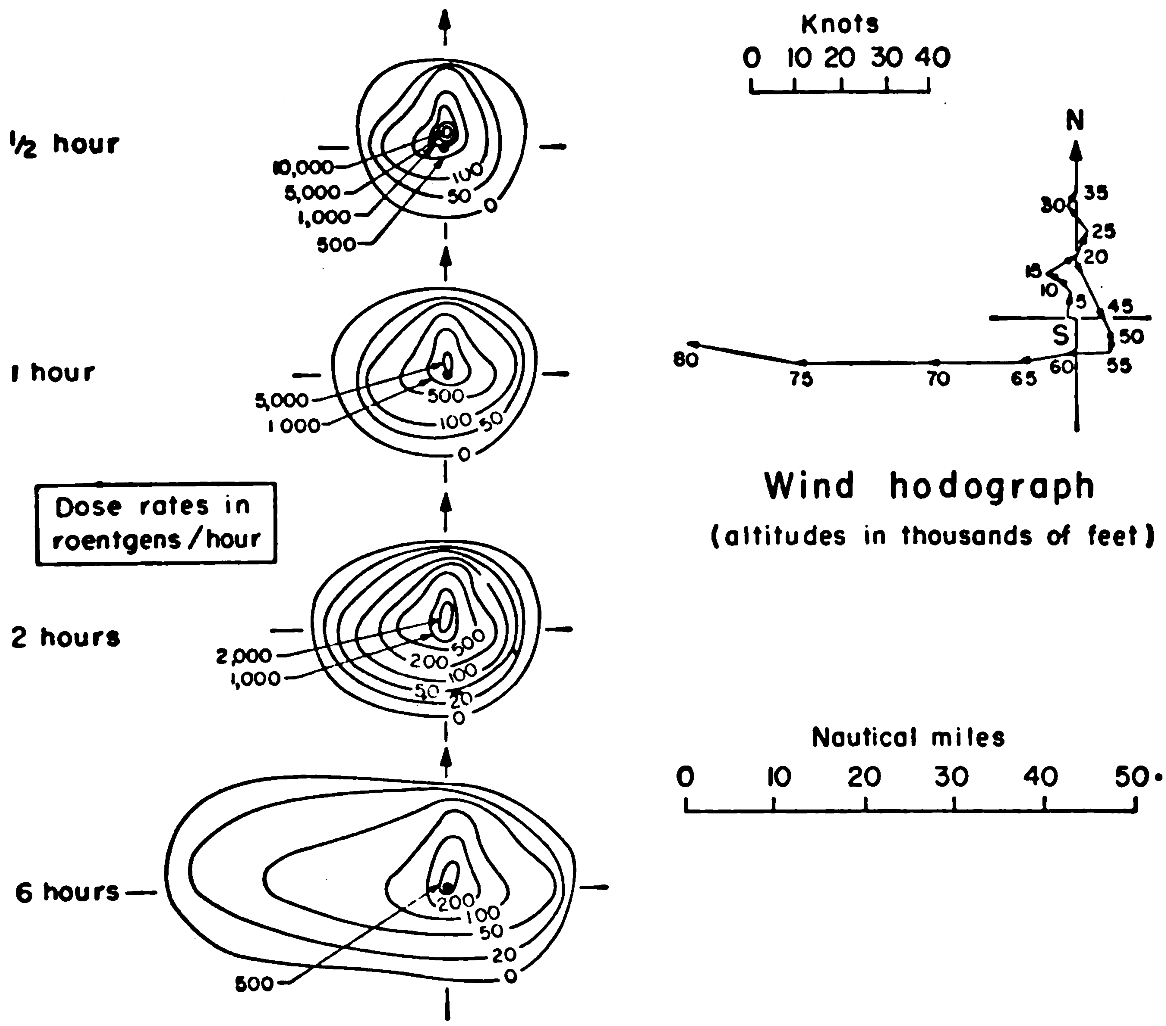

FIGURE 8.—Calculated fallout from a 1 MT surface burst with a two-thirds fission yield under a "low wind" condition. Winds are those for Atlanta on June 15, 1954.

FALLOUT FROM A BOMBING CAMPAIGN

No discussion of fallout would be complete without some discussion of the results of a bombing campaign, in which many bombs are set off against a target system with a large number of widely dispersed aiming points. Such a target system might be, for example, the industrial complex of the United States, or its system of airbases, providing targets which are located in a more or less random manner over the entire country.

The natural laws governing the fallout from such a campaign are the same as those governing the fallout from one burst. The difference lies in the fact that now the fallout patterns overlap in places and reinforce each other. Furthermore, where the ground zeros are fairly close to each other the fallout is more or less independent of the wind direction, since it makes little or no difference which bomb causes fallout on a given spot—such an area is "blanketed."

A number of studies have been made of such campaigns,[28] [29] and a technique has been developed by Greenfield for estimating on a probabalistic basis the results of fallout from multiple-bombs dropped randomly in a large area.[30] One such study, in which the hypothetical fallout was computed for an attack on the United States under a rather typical meteorological situation, was performed by Charles K. Shafer, headquarters, Federal Civil Defense Administration, Battle Creek. It was done in connection with the FCDA's Operation Sentinel.

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[28] Davidson, H. D., J. B. Green, J. B. Phelps, C. D. Stolzenbach: Fallout as a Threat from Attack by Manned Bombers, Operations Research Office, Johns Hopkins University, ORO–R–17, appendix C, September 1956 (secret).

[29] Rapp, R. R.: Fallout Computations for Operational Studies, Rand Corp., RM–1753, July 1956 (secret, R. D.).

[30] Greenfield, S. M.: Radioactive Contamination from a Multibomb Campaign, Rand Corp., RM–1607, January 1956 (secret, R. D.).

Though this represents just one particular combination of events, it is instructive to see what would have happened under this hypothetical attack, according to Shafer.

In this exercise about 250 nuclear (or thermonuclear) weapons with "damage zones" ranging from 3 to 5 miles were dropped on cities, industrial targets, and airfields through the United States. The combined fallout pattern from all these bombs is shown in figure 9. The details are contained in an unpublished report by the FCDA, and the following are some of the general conclusions which were drawn with regard to the effect of such an attack on the United States population:

	Dead	Injured	Uninjured
1st day	36,000,000	57,000,000	58,000,000
7th day	51,000,000	42,000,000	58,000,000
14th day	61,000,000	31,000,000	58,000,000
60th day	72,000,000	21,000,000	58,000,000

These numbers are based on 1950 population figures. Those dead on the first day were presumably killed by the immediate effects of the bombs, i. e., mostly blast and thermal effects. The subsequent rise in fatalities reflects the delayed effects of radiation damage, coupled in many cases to external injuries. While one should not take these actual numbers too literally, their orders of magnitude and the trends shown here are fairly realistic. In particular, the indication that fallout might account for a large number of deaths—nearly as many died by the immediate effects—is pertinent. In actuality, many of the "uninjured" ones would be caught by the fallout as they tried to move about. Clearly, however, such figures can only be illustrative, since the behavior patterns of the population would have a tremendous effect on the casualties due to radiation. While the meterorologist can predict to some extent the fallout patterns, he can hardly be expected to predict whether or not the population will be trained and provided with adequate shelters before such an attack.

Dr. KELLOGG. I am with the Rand Corp. at Santa Monica, Calif., at the present time. I am head of what we call the geophysics group. The geophysics group is composed to a large extent of meteorologists and atmospheric physicists, and we have been interested in studying the subject of radioactive fallout for a number of years.

I feel somewhat inadequate for the job of presenting all the material which I want to present today, partly because it is a complicated question, and partly because I feel that there is still some difference of opinion among meterologists on the details of this question of close-in fallout. I hope that I can not only reflect sort of a consensus of opinion, and my own opinion, but also indicate where we feel that we need to have more information on the subject of close-in fallout.

Before I start, I would like to make three rather general statements which in a sense are threads of the whole thing which I am presenting.

The first is one which I think you have already sensed from the testimony of Dr. Graves, to the effect that radioactive fallout is a major effect from an atomic explosion. I therefore feel that we should make all the pertinent facts available to the public and to the military on this question because one can't consider an atomic explosion and its effects without considering radioactive fallout.

The second point I would like to make very briefly is this.

Chairman DURHAM. May I ask a question at that point? Has your company been doing this all the time—making the information available to the public and also to the military?

Dr. KELLOGG. We have tried to very hard. In the January issue of the Journal of Meterology, for example, the work on close-in fallout

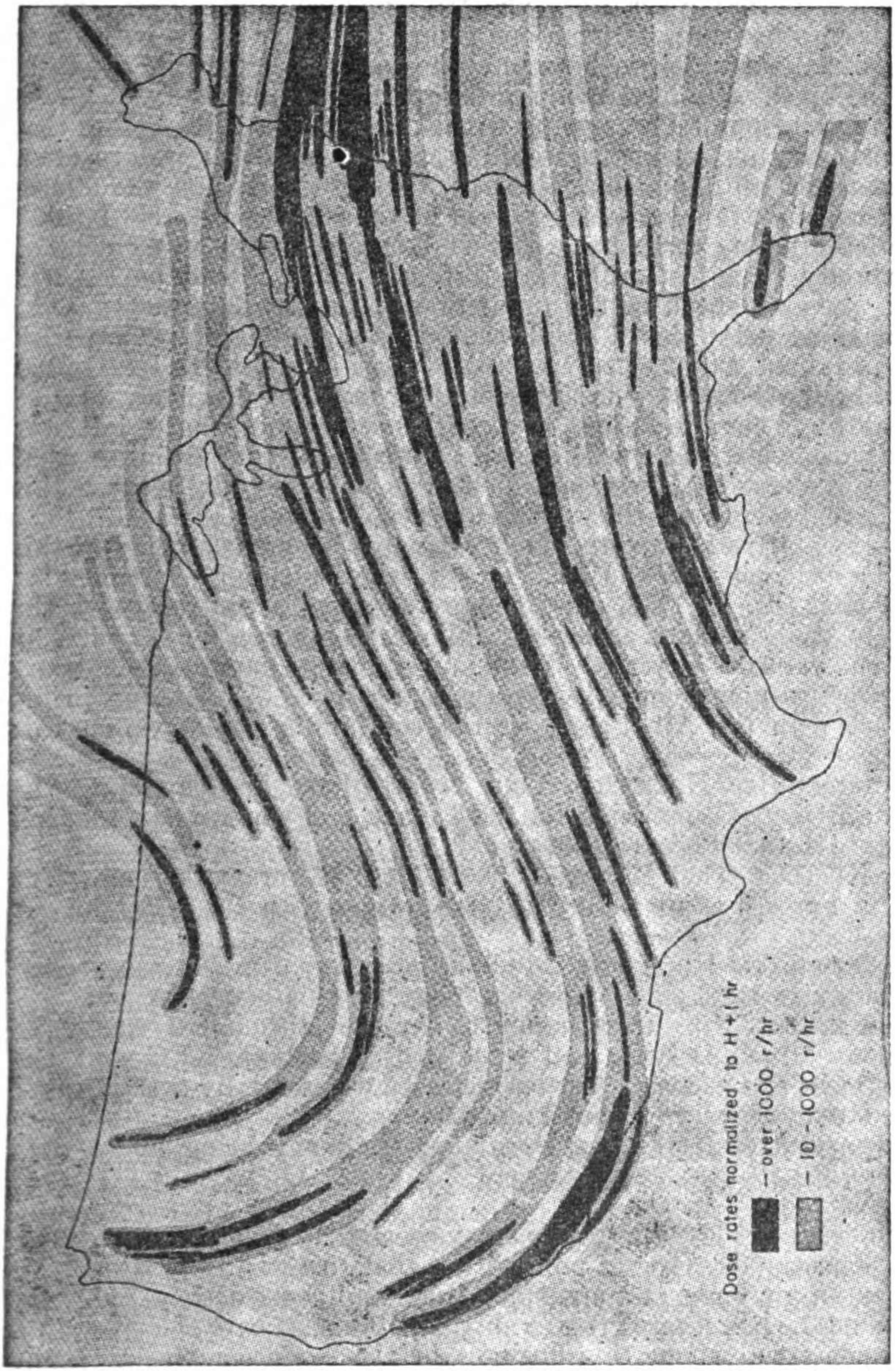

FIGURE 9.—Fallout condition computed by the FCDA for Operation Sentinel.

which our group has done was summarized. It is an article which appeared in what you might call the official United States meteorological journal by Dr. Rapp and Mr. Greenfield and myself. There have been other outputs from our group that have to do with other facets of fallout which we have published as fast as we could get them into the open. We have made an effort in this direction.

The second point I was going to make has to do with feeling that I think every meteorologist would share with me, that we are often charged with an impossible job of predicting exactly how the atmosphere will behave over a long period of time in the future. I think one of the points to be made is that there is always an element of uncertainty in a meteorological forecast. This should be kept in mind when we speak of the prediction of fallout patterns.

The third point that I think should be made in connection with close-in fallout is that when we speak of close-in fallout, as Dr. Graves pointed out, we must try to figure out how much of this material does come down in close-in fallout, because this determines what is left over to go worldwide. So I will spend a little bit of time defining what we know about the fraction which falls out close in, because this will have bearing on the worldwide problem, too.

Representative HOLIFIELD. Your company has made a study of this under a contract with the AEC or with the Defense Department?

Dr. KELLOGG. In 1953, our company accepted a contract with the AEC to study various aspects of fallout. This ran for 3 years. I believe it was 3 or 3½ years. We no longer operate under this contract. Our work is now primarily for the Air Force. Under our prime contract with the Air Force, we are continuing our work on this matter.

Representative HOLIFIELD. Your reports have been made to the Atomic Energy Commission for the 3 years, and you are now making reports to the Air Force; is that right?

Dr. KELLOGG. That is correct; yes. Most of our work is now for the Air Force, but we maintain close liaison with the AEC in our work.

Representative HOLIFIELD. Are you under any directions in regard to security in testifying before us today on this matter?

Dr. KELLOGG. No. I am happy to say that although I wrote the testimony which is here, and submitted it to both AEC and the Department of Defense, it has been cleared. Essentially everything I wanted to say they have allowed me to say.

Representative HOLIFIELD. Does your testimony bring up to date your findings?

Dr. KELLOGG. Yes.

Representative HOLIFIELD. You may proceed.

Dr. KELOGG. Dr. Graves pointed out that there is a big difference between an air burst and a surface burst and the fraction that falls out. Since he has covered this so ably, I will not go over this in detail. You understand about this business of the surface material being mixed in the fireball when the detonation is on the surface.

In the case of a tower shot, which is sort of an in-between case, the fraction which comes down is variable, in the complete report, in order to demonstrate how variable this is, I have taken some numbers which were given to me by Mr. Nagler, of the Weather Bureau, who has made a very careful analysis of the fraction which fell out from

five detonations, all of about the same yield. All had about 15 kilotons yield, and all were on the same height of tower.

The interesting thing was that they varied over a rather wide range in the fraction which came down. This, I think, is probably due to the fact that the meterological conditions and the way in which the tower was made, the amount of material around the test device, and so forth, all varied.

Representative HOLIFIELD. Do you mean by that that the fallout was uneven and in some places there was a heavier dose than others?

Dr. KELLOGG. This is true, of course. It is not just laid down uniformly. The thing which I was speaking of at the moment was the total fraction which comes down in the first 24 hours in the part of the country which is carefully monitored so we can keep track of it, in other words.

Representative HOLIFIELD. There was a great variation in the reading of your instruments?

Dr. KELLOGG. When all the information from all the instruments was in and analyzed, and the Weather Bureau or the Health and Safety Division was able to analyze this, they were able, as it were, to count up all the radioactivity over the entire area, and get a total budget. They knew how much went into the atmosphere. They were able to see how much came down. They could say that this was some fraction of the amount produced.

Representative HOLIFIELD. But that was in the nature of a fraction of the total fallout, and it was not a measurement of the degree of the dose in that area, or was it both?

Dr. KELLOGG. It was both. In order to determine the fraction which fell out, the thing which is measured is the dose.

Representative HOLIFIELD. What was your variance between the high dose and the low dose?

Dr. KELLOGG. Later on I can show you a chart—I am glad I came prepared with a chart—showing an example of just how it does vary in the test area.

Representative VAN ZANDT. Doctor, we have been talking about the fallout coming down and going up. For a kiloton yield, how many pounds of radioactive debris does it lift into the stratosphere?

Dr. KELLOGG. I don't know the number. You mean for a surface burst.

Representative VAN ZANDT. Yes; for a surface burst.

Dr. KELLOGG. I don't know exactly. I think Dr. Graves mentioned something about a ton per kiloton or something like that.

Representative VAN ZANDT. Dr. Graves said the figure he used would be debatable. The reason I ask the question is that Dr. Libby some months ago made a statement in which he said that for every 20,000 tons of TNT yield 2 pounds of radioactive fallout is lifted into the heavens. Then he went on to explain that within a matter of weeks most of it will have fallen out. Then he talked about the megaton yield, and how it was lifted into the stratosphere, and that it may remain there from a few seconds to 10 years. Would you concur in such a statement?

Dr. KELLOGG. These numbers, I think, are a little confusing, about the 2½ pounds per kiloton. I don't know what he was referring to Perhaps he meant radioactive debris.

Representative VAN ZANDT. That is correct.

Dr. KELLOGG. The important thing seems to be that the fraction of the total debris which is produced does not depend on the yield as much as it depends on the height of the burst. What I mean to say is this. We have a case in Nevada of a surface shot for which we could measure the dose around the countryside and make an estimate of the fraction of that low-yield device in Nevada which came down. The various estimates are produced here. It looked as though something like 80 or 85 percent of the material from that low-yield surface burst came down somewhere in the first 24 hours. Then in the Pacific, although it has been very hard until recently to estimate what this fraction was, during the last test a system for monitoring the oceans has been developed and by an analysis of this ocean monitoring again we are able to make a rough estimate of the fraction which comes down in 24 hours.

Again, although the estimates vary, a good estimate seems to be around 80 or 85 percent for surface bursts. This is over a very wide range of yields.

Representative COLE. When you speak of a surface burst, do you include a tower test?

Dr. KELLOGG. No; I do not. A tower seems to produce less fallout fractionwise. An air burst produces virtually no close-in fallout. Mind you, my subject is close-in fallout, so I will stick to this amount that comes down in the first 24 hours.

Representative HOLIFIELD. You may proceed.

Dr. KELLOGG. The meteorologists who are concerned with a study of fallout are naturally interested in how to keep track of the debris. I don't propose to give a lesson on how to compute fallout patterns. I think, though, that it would be constructive for the committee to know that these are four main schools of thought on how to predict or reconstruct fallout patterns.

The four main schools of thought—and I will show a chart in just a moment—all require one input, and that is the wind information. In order to tell the direction the fallout goes, the wind must be observed, and if it is a prediction, the wind must be predicted. This is an essential ingredient to any fallout calculation, obviously. In actually doing this, the wind all the way up from the ground to the height of the atomic Cloud has to be taken into account, since the particles start up high when the cloud stabilizes, and start to fall, and they spend a certain length of time in each layer as they wall. So the distance which they travel on their way to the ground will, of course, be the cumulative effect. We refer to this cumulative effect in terms of the integrated wind, as we measure it.

This integrated wind, or cumulative wind, up to some altitude is so essential to a fallout calculation that the Weather Bureau, at the request of the FCDA, has recently gone to a system of teletype messages twice a day from about 70 stations in which a kind of integrated wind appears in the regular wind transmission. This is to make the integrated wind immediately available in any Weather Bureau station in the country.

Representative COLE. Would you explain what you mean by integrated wind? I do not understand.

Dr. KELLOGG. Yes. I If I can take just a moment, I can draw a picture. Dr. Graves mentioned that we have all been teachers at one time or another, and we reach for a blackboard whenever we can.

The use of the word "integrated" is perhaps a little too fancy. It really means we are just adding winds together to get some sort of resultant wind.

If we can represent the wind at any one level by a vector, a particle traveling through this layer will travel in the direction of the vector, and it will go a distance proportional to the length of the vector. If it travels through this layer and falls down into the next layer, it will find itself then traveling with the wind at that layer. So it will start curving and follow that new path. Perhaps the wind at the next layer down will be different again. After we have added the winds at a number of layers together, we might have a curving path something like that, representing the horizontal projection of the particle's trajectory. We have added vectors, and we have gotten the resultant as the particles travel through a number of layers and finally reach the ground. This is what we would call the integrated wind, or the effective wind, the path which the particle finally took.

Representative COLE. Does that mean the mean of the wind influences?

Dr. KELLOGG. This is the total effect of the wind on the particle as it fell from the place it started to the ground. You might think of it as the "mean." I think that it would be fair to call it the mean effect.

This is an essential ingredient to any fallout calculation. I have a chart here which will show the four main schools of thought for computing fallout that I mentioned. Very briefly I will go over these various schools of thought.

Here I have sketched in a little vector addition such as I have on the board. This is the kind of thing which is very easy to compute. In general, no matter where the particles came from in the atmosphere, one of the integrated winds will be a line connecting the origin of the vector plot with the end of one of these vectors. Just by inspection of this little diagram you can see that no matter where the particle started from, it has got to be in this sector between the dashed lines. So this is just the simplest kind of fallout calculation. It merely says there is a "danger sector," and somewhere in there there will be fallout.

Chairman DURHAM. You are talking to what height?

Dr. KELLOGG. Our usual radiosonde wind flights go to 60 to 80 thousand feet, and with a big effort they can be made to go higher. This is usually high enough to establish where the danger sector will be. If very large yields were to be involved one might be interested in winds still higher than our usual radiosondes can go.

The next school of thought, if I can refer to it as that, is known as the "idealized pattern." I have not seen the new book which AFSWP has prepared, which you have in your hand. AFSWP has been one of the chief exponents of the idealized pattern. Essentially it started with the observation in the early days of fallout that fallout patterns often look sort of cigar-shaped, and it was tempting to try to characterize all fallout patterns as a simple elliptical shape with a circle around ground zero. Then various rules were established for shaping them, making them fatter or skinnier or longer or shorter, depending on the yield or the wind.

The idealized pattern is a very useful method where one wants to characterize fallout for planning purposes. But it has not found much

acceptance where one is interested in a prediction, because the predicted patterns are apt to be more unideal.

Representative COLE. Ideal from what standpoint?

Dr. KELLOGG. They can be characterized by a simple ellipse like this.

Representative COLE. I still don't understand what is intended to be the ideal.

Dr. KELLOGG. Idealized in the mathematical sense, I guess, in that you can characterize it in a sort of perfect shape.

Another method for predicting fallout patterns and one which appeals to meteorologists—because every meteorologist when he makes a forecast of weather looks at the present weather pattern and searches his mind (or his files if he is well organized) to try to find something like it in the past, and then he will say to himself: "What happened in the past will probably happen again, so I will use this back pattern or analog as a prediction tool. I will simply see what happened the day following that previous case which was like the case today."

An analog method could be used for predicting fallout if we had a big collection of fallout patterns, and the winds that went with them, and then we would just match winds and scales taking into account the yield and we would be able to have a fallout prediction. However, we have not had very many actual fallout patterns to look at. So we really have not been able to build up a real file of analogs. The only file of analogs that we can draw on is one which is computed theoretically. As a matter of fact, the Rand Corp. has published, unclassified, something which we call "the catalog of fallout patterns," on the basis of which one can begin to use an analog method for prediction.

The most complete characterization of fallout is usually started with what is known as a "fallout model." A few agencies have taken the bull by the horns and have set up very complicated computing schemes for tracing each particle down to the ground from each level, each particle size, and adding up the effects on the ground. Of course, no one computing scheme could actually trace each particle, but there are shortcuts, and various agencies have developed practical computing schemes based on some kind of a fallout model, which reproduces the fallout as accurately as it can be done by theoretical methods.

Representative HOLIFIELD. Let me ask you this question. There are a number of these patterns in the AFSWP book.

Dr. KELLOGG. Idealized patterns.

Representative HOLIFIELD. There is an idealized pattern here. There are different kinds of patterns in here. I notice that in 1954 high yield explosion at Bikini that it gives a long pear shaped pattern. It starts out with a 5,000 roentgen yield and it goes at the end of 60 miles to 3,000, and at a little over 100 miles it is 2,000 roentgens, at 130 miles it is 1,000 and at 160 miles it is 500. That is at 36 hours.

Dr. KELLOGG. Mr. Chairman, these are probably cumulative doses, aren't they?

Representative HOLIFIELD. Yes, over the 36 hours. I was going to ask you about that. Dr. Graves spoke today about receiving 200 roentgens. As I remember the description of that accident, it was just for a moment. The question I want to ask you is this: Would 200 roentgens received in an instant be equivalent to 200 roentgens received over a longer period?

Dr. KELLOGG. This is a biological question. I prefer not to answer this in any detail. My biologist friends tell me that there is a certain amount of leeway there in the time in which one could accept it. If you get it within a relatively short time like a few hours, it is equivalent to getting it all at once. This is something which I think the biologists should comment on.

Representative HOLIFIELD. Very well.

Dr. KELLOGG. In order to give you a feel of what actually happens under fallout conditions, I have three charts which I can go through very quickly. They were prepared following the open or civil defense shot on May 5. This is a chart which was prepared by Mr. Nagler, who has made a detailed study of the fallout from a number of the tests in Nevada.

This first chart (p. 114) shows the fallout from the May 5, 1955, civil defense or open shot, which was roughly 30 kilotons on a tower. This is a map showing a few of the landmarks, Goldfield, Tonopah, Warm Springs, and so forth. You notice the scale of miles here, 60 miles as the total scale. In red is the observed fallout as deduced from an extensive system of road monitoring and from a few aircraft observations in that area. You see it goes out several hundred miles.

This little red line here is 100 milliroentgens per hour at 12 hours. The next red line is 10 milliroentgens per hour at 12 hours, and the outside one is 1 milliroentgen per hour at 12 hours. These blue lines here were a noble attempt to reconstruct the fallout taking into account all the wind observations at the time, and a careful synoptic analysis of the fallout. Here you can see the blue and red lines following fairly close to each other, the 10 and 10 and the 100 and 100. You can see the close-in fallout was reproduced quite well. In fact, the general curvature of the pattern toward the east was reproduced very well. It is important to note the curvature toward the east, because this is the kind of thing I was talking about when I said that a meterological forecast is a tough thing.

Representative COLE. Before you take the chart down, does the blue line indicate the forecast of the weather people with respect to the wind?

Dr. KELLOGG. No. This is a reconstruction. The next chart (p. 113) shows a forecast.

Representative VAN ZANDT. Did this fallout move as a mass and did it continue to move as a mass, or did it break up eventually?

Dr. KELLOGG. In this case it continued to move as a mass. In other words, it started falling here close to ground zero first, and then it was laid down in a fan shape curving to the east. It occurred earlier close in and later and later as you go along in the pattern. Heavy particles were landing close in, and lighter particles which drift longer landed further out.

This next chart (p. 113) is a prediction. This is the Weather Bureau's prediction, using the winds predicted at 2 hours before shot time. I think this is the kind of thing that one would expect. Very good verification in close. After all, this is where it is important. But then it was pretty hard apparently, in this case to predict the later shift, which must have occurred as much as 12 hours later.

Representative COLE. Is your scale the same in this chart?

Dr. KELLOGG. Yes. The scale is exactly the same. It is the same map. The red lines are exactly tracing the red lines you saw before.

Just to show the Weather Bureau is not the only outfit making predictions, this was the Los Alamos Scientific Laboratory and the University of California Radiation Laboratory prediction. They also have a forecast team of meterologists. Here again the prediction made at 2 hours before the shot time showed the early fallout within the hundred milliroentgen per hour at 12-hour line to be fairly well verified, at least in the direction in which it went. Again they did not get the curvature of the later fallout.

Chairman DURHAM. What would be your observation as to the accuracy there in the predictions by the Weather Bureau and the other outfit? It looks to me they are off quite a bit in the prediction, because the observation line there cuts back pretty quick, and the other continues on up.

Dr. KELLOGG. The early part, as I say, in both cases was fairly well verified, but neither of them anticipated the shift of the wind which occurred later on. I think this is what one would expect. The meteorologists don't fool themselves as to how well they can predict the wind. There are a number of studies of this matter. One of the best ones recently was by the Air Weather Service, which gives actual wind statistics and forecast statistics. Recently, Jack Reed, a meterologist with the Sandia Corporation, has made a study of this situation and applied it directly to Nevada, the purpose being to try to assign some kind of probability to a forecast made a certain number of hours before shot time. Meteorologists recognize that any forecast is a kind of probability. It is an educated guess. This effort by Reed is a very noble effort to actually assign the right kind of probability to such a forecast, so that the people who have to use the forecast can know with what certainty the forecast was made.

Representative COLE. How do you account for the fact that the forecast of the direction of the fallout was reasonably accurate, but the forecast of the breadth or width of the fallout was quite inaccurate?

Dr. KELLOGG. I don't know the details. I did not sit down and go through exactly the assumptions that were made in each of these models by these people. I can only say that it would have something to do with the model they took, that is: How big a cloud they assumed, which would determine how wide the pattern was; how the radioactivity was distributed with height; the fraction which fell out, which we were talking about earlier—any of these might not have been predicted accurately. As I mentioned earlier we are uncertain about this fraction when we are firing in a tower. Any of these assumptions could have had an effect on the width of the predicted pattern.

Representative COLE. But the analyzers did know in advance the estimated yield of the test, did they not?

Dr. KELLOGG. Yes. Even though you may know the yield for a tower shot, you may not know the fraction of this yield which takes place in the early fallout with any accuracy, nor how it is distributed with height and particle size. These could have accounted for this changing shape.

Representative VAN ZANDT. Both groups had the same data as far as weather was concerned in that part of the world.

Dr. KELLOGG. Yes. They both used the same wind prediction.

Chairman DURHAM. In other words, they are pretty good up to a hundred miles, but beyond that it is not too accurate?

Dr. KELLOGG. That is the way it looks here, and that is the way it would always tend to look where we have a difficult forecast situation. This is probably a very light wind condition. The distant parts are really rather unimportant. I might mention here, as I recall, that the farthest extension of the 100 milliroentgen per hour line on this chart represents a "lifetime dose"—that is, the accumulated dose you would receive if you stood out in the open from the time it came down to infinity—of 9 roentgens. At this point on the 10 milliroentgen per hour line it is much less. It is a fraction of a roentgen.

Representative HOLIFIELD. You have not given us the strength of that particular weapon.

Dr. KELLOGG. About 30 kilotons on a 500 foot tower.

Representative VAN ZANDT. Doctor, are you in a position to tell us how long you actually followed that cloud?

Dr. KELLOGG. I am sure it was followed. I don't remember the details. An attempt is made for radiological safety purposes to trace where the cloud went by meteorological analysis. This is something which we have done quite a bit of at Rand. I don't remember whether we analyzed this one particularly or not. It is possible to do it by just analyzing the winds. It is also possible to do it by monitoring it by aircraft.

Representative VAN ZANDT. Is that your field, monitoring the cloud by aircraft?

Dr. KELLOGG. No, that is not.

Representative COLE. Would you repeat the dosage at 10 miles out? Would you state again what that is?

Dr. KELLOGG. Let up put this first chart (p. 114) back up which has the scale of miles. Let me make sure I have the right numbers here.

This point here—the furthest extension of the 100-milliroentgens-per-hour, 12-hour line—represents an infinity dose of 9 roentgens. That is about 30 miles from ground zero.

Representative COLE. Tell me what you mean by an infinity dose of 9 roentgens.

Dr. KELLOGG. By reconstructing the pattern and also by certain instruments which note when the thing starts, we can tell when the debris arrives at the ground. It doesn't all arrive at once, but it arrives within a relatively short period of time. Then, if we had an instrument which just simply counted roentgens, and it was hung on a post 3 feet above the ground and stayed there from then to doomsday, it would fiinally accumulate 9 roentgens. That is what we mean by infinity dose. Of course, most of this 9 roentgens would be accumulated in the first few days.

Representative COLE. What is the influence which determines the period of accumulation other than wind?

Dr. KELLOGG. The wind determines when it starts. The total dose then depends on the amount which comes down, and when it came down.

Representative COLE. Suppose it got there at this point and there was no wind at all.

Dr. KELLOGG. It would hardly get there if there were no wind at all.

Representative COLE. I still do not understand what you mean by a 9 roentgen perpetuity dosage.

Dr. KELLOGG. I can draw it perhaps as a time plot. (At the blackboard). This is the dose rate in roentgens per hour on the vertical scale. Here is the time on the horizontal scale. We said this was for a point about 30 miles out from ground zero. Suppose there was a 10-knot wind, so about 3 hours after shot time we begin to get fallout. The dose rises at 3 hours, and suppose it falls for the next hour and then stops. That is probably what would have occurred, fallout occurring for about an hour while the cloud is passing by. Then decay starts. This is radioactive decay at the rate that Dr. Graves gave, according to the time-to-the-1.2 power law, where time is measured from shot time. If this were the rate at 3 hours, and if we go to 7 times that, or 21 hours, it would be down by a factor of 10. After another 7 times 21 hours, whatever that is, the dose rate would be down to a hundredth. If we counted up the total number of roentgens, that is, multiply the dose rate times the time for each time interval and sum over all the intervals, we would get a cumulative dose. If we calculated this out on the tail of the curve to an infinite length of time, we have what we call an infinity dose. As you can see from here, most of this infinity dose is obtained in the first day or so in this case.

Representative COLE. I think I understand. At least I do better than I did before.

Dr. KELLOGG. I admit it is a difficult concept at first, but it is one which the people who are working with fallout sometimes use. They prefer to use an infinity dose instead of a dose rate at some time. It is merely a matter of what you want to talk about.

Representative HOLIFIELD. Dr. Kellogg, how far are you on your summary? I understand that you can be with us tomorrow, and, if it is very long, I want to carry you over until tomorrow. If it is short, since it is 5:30 and the members have to get back to their offices——

Dr. KELLOGG. I would like to take a little bit longer, 10 or 15 minutes, if that is all right for you, so perhaps tomorrow would be better. What I have to present still, I think, is fairly pertinent.

Representative HOLIFIELD. We do not want to cut you out of any time. I suggest that we start with you tomorrow and, in the meantime, it will give the staff some time to look at your prepared presentation, and we may have some more questions for you.

Dr. KELLOGG. This was a good stopping point, anyway.

Chairman DURHAM. I might say this is my first lesson in meteorology.

Representative HOLIFIELD. The Chair will announce that the committee will resume its hearings tomorrow morning in room 457 in this building. There will also be a 2 p. m. session tomorrow. Wednesday, we will come back to this room again. The meeting stands adjourned.

(At 5:25 p. m., Monday, May 27, 1957, a recess was taken until Tuesday, May 28, 1957, at 10 a. m.)

THE NATURE OF RADIOACTIVE FALLOUT AND ITS EFFECTS ON MAN

TUESDAY, MAY 28, 1957

CONGRESS OF THE UNITED STATES,
SPECIAL SUBCOMMITTEE ON RADIATION OF THE
JOINT COMMITTEE ON ATOMIC ENERGY,
Washington, D. C.

The special subcommittee met, pursuant to recess, at 10:05 a. m., in room 457, Senate Office Building, Hon. Chet Holifield, chairman of the subcommttee, presiding.

Present: Representatives Holifield, Durham (chairman of the Joint Committee), Price, Dempsey, Van Zandt; Senators Pastore, Hickenlooper, and Bricker.

Present also: Professional staff members James T. Ramey, executive director; George E. Brown, Jr., Hal Hollister, staff technical adviser, and Paul Tompkins, consultant.

Representative HOLIFIELD. The committee will be in order.

Today we open our second day of the hearings on the nature of radioactive fallout and its effect on man. Yesterday we began our hearings with an introductory statement by Dr. Charles L. Dunham, Director of the Division of Biology and Medicine of the Atomic Energy Commission, in which he provided some perspective on the general radiation problem as a basis for the beginning of the hearings. He was followed by Dr. Mark Mills, associate director of the Livermore Laboratory of the University of California, who provided us with technical background information on radioactivity and radiation and the hazard aspects of controlled fusion and fission reactions.

Yesterday afternoon, Dr. Alvin C. Graves, chief of the testing operations of the Los Alamos Scientific Laboratory, provided more detailed information on the production of radiation and radioactivity by the detonation of nuclear weapons. He described the effects of immediate bomb detonations, together with local fallout and worldwide fallout. He also gave some indications of the nature of the fallout from so-called clean and dirty weapons.

Dr. Graves was followed by Dr. Frank Shelton, of the Armed Forces special-weapons project, and Gen. Alfred D. Starbird, Director of the AEC Division of Military Applications, who provided a few comments on Dr. Graves' testimony and the new book, The Effects of Nuclear Weapons.

Incidentally, General Starbird indicated that the printed statement entitled "Testimony Before the Joint Committee on Atomic Energy on the Production of Radiation and Radioactivity From Nuclear Weapons—Topic V" was his statement, which he submitted for the record. The chariman and committee were under the impression that

this statement, distributed prior to Dr. Graves' testimony, was the testimony of Dr. Graves, since they were somewhat similar. We were given a carbon copy of the statement which Dr. Graves used as a basis for his oral presentation, and are having it reproduced for the information of the subcommittee. It is hoped that the Commission will identify their statements in a better fashion hereafter.

Our last witness yesterday was Dr. W. W. Kellogg, of the RAND Corp., who began his testimony on the atmospheric transport, storage, and removal of particulate radioactivity, particularly local fallout debris.

Dr. Kellogg did not complete his testimony yesterday, and we are happy to have him with us again today to resume his testimony.

Dr. Kellogg, will you please come forward? You may proceed where you left off:

STATEMENT OF DR. W. W. KELLOGG, OF THE RAND CORP.—Resumed

Dr. KELLOGG. Mr. Holifield and members of the committee, perhaps I should start by recapping just very briefly what happened yesterday, and perhaps making it a little bit clearer. I would like to very briefly mention the fact that the scientists who have been interested in studying fallout have been in fairly close touch with each other, and last March about 60 of us assembled in Santa Monica, Calif., to try and iron out some of the points of difference that we had.

Chairman DURHAM. You say 60 people, Doctor. Whom do you mean?

Dr. KELLOGG. Sixty people representing the various agencies, such as the AEC, the Air Force, the Army, the Navy, and various civilian agencies who have all been connected in one way or another with studies of fallout.

Chairman DURHAM. Was there a report made by that group?

Dr. KELLOGG. The report is being prepared. It will be classified when it comes out, because we wanted to discuss specific tests. Therefore, it is classified. However, there was one thing which we could all agree on at the end of the session, and that was that we had a long way to go before we could all get a consistent and clear picture of this process of radioactive fallout.

In particular, I think it should be mentioned that the fraction of fallout from a surface burst, which I gave yesterday as around 80 percent, in my opinion, was discussed at great length at this meeting, and it was shown that the evidence which we have for this fraction which falls out from a surface burst is not clear, and that we really are not certain about the fraction which falls out. We know that it is roughly 50 percent, plus or minus some number of percent, and the 80 percent which I gave you is sort of a best guess that RAND has made. I do not think that I should say this is a certain number by any means. I wanted to make that clear.

Representative HOLIFIELD. The 80 percent goes into the stratosphere?

Dr. KELLOGG. The 80 percent is what falls down in the first 24 hours or so. It would leave 20 percent to stay in the air.

Representative HOLIFIELD. This only refers to bombs, where the column does not go into the stratosphere?

Dr. KELLOGG. No, sir. This is more or less independent of yield, I would say. We have an observation of a low-yield weapon, and we have some other observations of higher yield weapons; and the fraction which falls out in early fallout does not seem to be very sensitive to yield.

I think the important difference, and one which I think will be taken up by Dr. Machta, who is following me, is that when we have a low-yield weapon the cloud does not go very high; therefore what is left is at a relatively low level in the troposphere, which is the lower part of the atmosphere. When we have a high-yield weapon, then what is left is higher in the atmosphere, in the stratospere.

The fraction of the debris taking part in the close-in fallout depends on whether it was a surface burst or not. How high it goes depends on the yield.

Representative HOLIFIELD. For the purposes of clarification, will you please explain what you mean by the troposphere?

Dr. KELLOGG. Yes, sir. The troposphere in middle latitudes where we are now is the atmosphere from the ground up to about, say, 30,000 to 40,000 feet. It is the part of the atmosphere that contains clouds, contains the weather as we know it.

Representative HOLIFIELD. And in the Tropics, it would go up to about 50,000?

Dr. KELLOGG. 50,000 to 60,000 feet in the Tropics; yes, sir.

Representative HOLIFIELD. And above that is the stratosphere?

Dr. KELLOGG. That is right.

I will not belabor this point. I just wanted to indicate there is some uncertainty about this number.

Yesterday we showed charts from the May 5, 1955, open shot in Nevada, a shot of roughly 30 kilotons on a 500-foot tower. The motive for showing the fallout from this particular burst was to give the committee a little bit of feel for the irregularity of one of these fallout patterns, and to show that various ways of predicting the fallout had been developed; that the predictions close in where the fallout is heavy enough to be important is fairly accurate, whereas further out, where the fallout is relatively unimportant the predictions are less certain.

I think in Nevada the fallout patterns are particularly irregular because of the terrain features which break it up. The rugged terrain also makes it hard to observe the fallout pattern.

So the red line which I showed on that chart representing the "observed" fallout is only roughly known. If we had a complete map, we would see it marching up across the mountains and down into the valleys, and we know these have an effect upon fallout. It would not be a smooth line as I showed it.

Representative HOLIFIELD. Would you say the area is such adjacent to the explosion point of these weapons to give the maximum opportunity for local fallout?

Dr. KELLOGG. That appears to be the case; yes, sir.

The hundred milliroentgen per hour line at 12 hours, which was shown on the chart, only went out about 30 miles in a due-north direction, and this early fallout, of course, can be forecast fairly well.

There are two further topics which I would like to take up, which I did not have a chance to yesterday.

One has to do with the growth of the pattern in time. I think we have not really discussed the growth in time of the pattern. We have

tended to look at these patterns as if they were laid on the ground with a big rubber stamp, whereas I think you all understand that the pattern develops over a period of time because the debris arrives at different places at different times in a more or less orderly process.

In particular, the question of when the fallout occurs close in to ground as zero, I believe, requires a little bit of attention, since in an emergency this would have an important bearing on what plans one would take to get out of the fallout.

In preparation for this hearing I collected all the data I could get from the tests which had a bearing on this question of when the fallout begins relatively close in to ground zero; and by relatively close in, I do not mean just a few thousand feet. I mean at distances ranging from 8 to, say, 30 miles, from ground zero for large yields, where the atomic cloud is quickly overhead. That is, this is the fallout which is in the shadow of the mushroom cloud.

It appears from a collection of data, which are summarized in the report which I presented for the record, that the fallout close in does not generally begin for about 30 minutes. The times of arrival actually vary from 20 to about 40 minutes. I think this is significant, and I think the explanation is rather easy to see. If one visualizes the fact that most of the debris is carried up in the mushroom cloud, then when the mushroom cloud stabilizes it takes a while for this material to get back down to the ground. So this delay seems reasonable, and I have documented it with the data which we have from the atomic tests.

The second part, having to do with the growth of the pattern in time, I think, can best be illustrated by this chart which, incidentally, is taken from the unclassified article in the Journal of Meteorology, written by Dr. Rapp, Mr. Greenfeld, and myself. So this is familiar to meteorologists who have read the journal article.

This chart shows a succession of fallout patterns at various times: First, a half hour, 1 hour, 2 hours, and 6 hours. It is from a 1-megaton explosion, and it is assumed there is two-thirds of a megaton of fission products represented in this fallout pattern. (See p. 116.)

The dose rates represented are in roentgens per hour at the time of the pattern.

I believe this is instructive in showing the way in which the pattern grows, in showing that it is most intense when it first comes down, and then decays after it is on the ground.

Close in we have the inside line, the thousand roentgens per hour at a half hour. The next line is 500. In other words, judging from the numbers which we heard yesterday, if this dose were to be imagined to be steady, at roughly half hour you would get a lethal dose in something like an hour.

Representative HOLIFIELD. For how many miles?

Dr. KELLOGG. The scale of miles is here. The 500 roentgen line at a half hour extends out, I would judge, about 12 miles.

Representative HOLIFIELD. In other words, in one-half hour everything within 30 miles downwind—is it 12 miles or 30 miles?

Dr. KELLOGG. Twelve miles.

Representative HOLIFIELD. Twelve miles downwind would receive a lethal dose of 500 roentgens?

Dr. KELLOGG. Yes.

There is one thing which was not taken into account in this calculation because it was done before we had really studied the time-of-arrival business. It appears that at about half an hour this blanket of fallout material descends on the ground, and so that at half an hour it is sort of nip and tuck whether the fallout has arrived yet or not. This half-hour picture might really refer to something like 40 minutes, but I do not think we know enough to make a clear distinction.

Senator BRICKER. What about the wind currents at that time?

Dr. KELLOGG. The wind current was a fairly strong west wind, and the wind did not change much with altitude in this case. So it is being laid out in an easterly direction at a fairly rapid clip.

Senator BRICKER. What do you mean by "fairly strong" winds—20 miles?

Dr. KELLOGG. In the original article there is what we call a hodograph showing the winds. I did not reproduce it on the chart, and perhaps I should. I can tell you roughly what they were.

Senator BRICKER. That is what I want, just roughly.

Dr. KELLOGG. They roughly range from about 40- to 80-knot winds in this case. Fairly windy day at high altitudes.

Representative HOLIFIELD. Would you explain at this point why you have on the chart there "1 megaton yield" and then "two-thirds megaton fission yield"? Would you give us a clarification on that?

Dr. KELLOGG. This represents the fact—and it is merely for illustration purposes only, of course—that this was a thermonuclear device in which part of the yeld came from the thermonuclear reaction.

Representative HOLIFIELD. Part of the blast yield?

Dr. KELLOGG. Part of the blast yield.

Representative HOLIFIELD. Or the heat yield?

Dr. KELLOGG. That is right.

Representative HOLIFIELD. Therefore, you figure roughly you would lose a third, that the megaton would not be completely a 1 megaton of fission?

Dr. KELLOGG. That is right.

Representative HOLIFIELD. One megaton of radioactive fission, but it would be two-thirds of a megaton in the fission products, and the other third in blast and heat?

Dr. KELLOGG. No, sir, that is not quite the way to say it, sir.

The total energy yield and thermal yield in terms of the work put out by the explosion was 1 megaton. However, only two-thirds of a megaton of fission products were released. And the conversion there from megatons of work to megacuries is the thing which Dr. Graves discussed yesterday, how to do this. As I say, this is for illustration only.

Representative PRICE. Mr. Chairman?

Representative HOLIFIELD. Mr. Price.

Representative PRICE. You will probably cover this before you get through with the chart. With an increasing yield, how does the figure over there on the half-hour basis expand, or how does this work if you drop a 10-megaton bomb?

Dr. KELLOGG. The way in which this pattern changes with yield, seems to be in such a way that the area within any one of these contours goes up with the yield. The areas go up linearly with the yield.

Representative PRICE. What would that 500 figure be on a 10-megaton bomb?

Dr. KELLOGG. There would still be a 500 line on the 10-megaton bomb, but it would be 3 times bigger in any dimension. It would have an area 10 times bigger.

Representative PRICE. It would have an area, say, of about 40 miles?

Dr. KELLOGG. Yes; that is about right. I would rather point to the 1-hour pattern because there is a question as we raise the yield, this question of whether this material gets back down to the ground in half an hour. I expect it would not for a 10-megaton yield. It probably would for 1-megaton yield. That is because of the difference in altitude.

Let's look at the 1-hour pattern, and talk about that. I prefer that to the half-hour pattern, particularly if we wish to discuss the way in which it scales with increasing yield.

Representative PRICE. On the 1-hour one, you have 500 roentgens still extending pretty close to 12 miles?

Dr. KELLOGG. Yes; it is. It looks like it was about 10 miles.

Representative PRICE. So, if you had a 10-megaton drop, the 500-roentgen area would be at least 40 miles?

Dr. KELLOGG. That is true; yes. The square root of 10 is a little over 3.

Representative HOLIFIELD. Now, in areas in the case of warfare where cities are close together that are primary targets, you would also face the factor of lapping, would you not?

Dr. KELLOGG. Yes.

Representative HOLIFIELD. And that would increase the radioactive fallout to the extent that the degrees of lap would add?

Dr. KELLOGG. That is true.

If I may, I would like to show a chart in which the fallout from a multiple-bomb campaign is shown. (See p. 119.)

Dr. KELLOGG. Now that we have had time out for the scene moving, I would like to say that this chart was prepared by Mr. Charles Shafer of the Federal Civil Defense Administration headquarters in Battle Creek, Mich., and he has very kindly let me borrow this chart, which was prepared for the FCDA's Operation Sentinel.

Representative HOLIFIELD. Would you make an estimate as to the pictorial authenticity of this, based upon scientific information?

Dr. KELLOGG. Yes. This kind of a fallout chart has been done as an exercise many times.

Chairman DURHAM. It was actually——

Dr. KELLOGG. Mr. Shafer is in the audience, and if you press me on the details, I will perhaps ask permission to have him help me.

Representative VAN ZANDT. It would be nice to have Mr. Shafer up here.

Representative HOLIFIELD. Yes, let's have Mr. Shafer up here at this time.

Dr. KELLOGG. Fine. I would like very much to have him up here.

Representative HOLIFIELD. Mr. Charles Shafer. We are happy to have you before the committee this morning. The committee would like to hear briefly the substantiation from a scientific standpoint of this chart which you have prepared, and its meaning.

STATEMENT OF CHARLES SHAFER, METEOROLOGIST, UNITED STATES WEATHER BUREAU (ON ASSIGNMENT TO FCDA)[1]

Mr. SHAFER. This particular fallout analysis is purely hypothetical, which is obvious. It is based upon one of the techniques which Dr. Kellogg explained to the committee yesterday, the stylized pattern technique, and it is virtually identical to that which is described in the AFSWP paper, copies of which were entered into testimony yesterday.

The meteorology used on this particular fallout analysis was the wind existing from 80,000 feet altitude, down to the surface of the earth during the period November 20 to 21, 1956.

In actuality, if such an attack or an attack of this magnitude——

Representative HOLIFIELD. Will you please repeat the date? Some of us did not hear that.

Mr. SHAFER. November 20 to 21, 1956, a 24-hour period.

This represents an attack of total yield of approximately 2,500 megatons, a very large attack. It is an estimate. It is an analysis based upon many assumptions such as Dr. Kellogg described yesterday. In an actual attack of this magnitude, certainly the levels of radiation would vary considerably from those indicated on this chart, simply because we do not know all of the information we need to know in order to do such an analysis as this is on a forecast basis.

Representative VAN ZANDT. What type of attack was it?

Mr. SHAFER. This was an attack of thermonuclear weapons.

Would you like to have some information on the size and the distribution of weapons?

Representative VAN ZANDT. As long as you do not enter the classified field.

Mr. SHAFER. There is no classification involved in it.

The weight and distribution: The weapons were of three sizes: In the range of 5-megaton yields; 10-megaton yields; and 20-megaton yields. There were 250 bombs, with a total yield of about 2,500 megatons. There were 144 areas of attack. Fifty-three of the areas were basically population and industrial centers; 59 areas were basically military installations; and the remaining 52 areas contained both military and population objectives.

Representative VAN ZANDT. How many minutes or hours were involved?

Mr. SHAFER. In the attack?

Representative VAN ZANDT. Yes, in the attack.

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[1] Waverly, N. Y., graduated from State Teachers College at Albany in 1939 and did graduate work in mathematics and meteorology at American University and New York University.

Assigned to Federal Civil Defense Administration by the Weather Bureau in April 1955 to assist in radiological defense problems resulting from phenomena of fallout. Began meteorological career as weather observer at Raleigh, N. C., prior to World War II. Flight weather forecaster at Dayton Army Air Field and consultant to Accelerated Service Testing Branch of U. S. Air Force. One year scholarship at College of Engineering of New York University. Subsequent to this Mr. Shafer was detailed to International Civil Aviation Organization at Montreal for a special research project, then to Washington National Airport as an international forecaster.

Next he was assigned to Weather Bureau-Air Force-Navy Analysis Center and in 1952 was loaned to CAA and transfered to Europe to plan and supervise the rehabilitation of the Greek Weather Service. In 1954 Mr. Shafer received 3 months of specialized instruction in long-range forecasting and worked as supervising meteorologist at the Military Weather Bureau unit at Suitland, Md.

Mr. Shafer transferred from the Weather Bureau to the Radiological Defense Operations Office of FCDA and will work with other governmental agencies in developing a national radiological monitoring network. (Submitted by Federal Civil Defense Administration.)

Mr. SHAFER. Approximately 2 hours for the delivery of the attack, sir. The fallout analysis was carried on for 24 hours. We assumed that there was sufficient fallout debris to render the analysis valid to carry it out for 24 hours.

One thing I should mention is that the analysis of the east coast is probably erroneous. It would have been better to have terminated the line at the coast, simply because debris in the ocean area is subjected to considerable mixing by ocean currents, and there would have been considerable dilution. However, from our analysis this is an indication of what would have come down. It would not have remained in that location, as it would have been more apt to do on the ground.

Representative VAN ZANDT. Will you mention some of the targets, and give the geographical distribution of them.

Mr. SHAFER. Yes. We gave the Air Defense Command credit for quite a few knockdowns on this. This represented the results of the aircraft which were able to penetrate our borders and deliver their weapons as indicated.

The heaviest concentration, the heaviest complex of detonation happens to be in the Detroit area, because we made some assumptions not only with regard to enemy intent in getting to target, we also assumed there were some knockdowns of aircraft and some unintentional weapon detonations.

In the Detroit area, for example, there are some 70 or 80 megatons of detonation of weapons within 15 or 20 miles of one another. Consequently, there is a tremendous overlap from Detroit eastward across Buffalo and across central New York State—the factor Mr. Holifield mentioned a while ago, the factor of overlap.

Chairman DURHAM. What is the yellow?

Mr. SHAFER. The yellow shading, sir, represents the areas of most intense radiation hazard, and area where the dose rate normalized back to 1 hour after detonation would have exceeded 3,000 roentgens per hour.

The red areas are where the radiation levels would have exceeded 1,000 roentgens per hour. The blue areas are where the radiation levels would have exceeded 100 roentgens per hour. The green levels are where the radiation would have exceeded 10 roentgens per hour.

Would you be interested in the effects of this particular attack as far as people are concerned?

Representative HOLIFIELD. Yes. What was your estimate on the loss of human life?

Mr. SHAFER. May I read that, sir, so I will have it correct?

Without evacuation of the target cities to escape primary weapons effects—that is, to escape blasts, thermal and initial radiation effect——

Representative HOLIFIELD. I did not get that.

Mr. SHAFER. Without target evacuation, target area evacuation to escape primary weapons effects, and assuming present-day shielding which exists in the United States, that is, homes, or home basements, or the basements of large administration buildings, the bomb-damage assessment on this particular attack indicated a total loss by death of about 82 million people, based upon current United States population, and about 24 million surviving casualties, 60 days subsequent to the attack. This left about 60 million relatively uninjured, but doubtlessly suffering some radiation effects.

In this particular analysis, we only carried it down to the 10 roentgens per hour. So that even in the white areas, where the levels are relatively low, there could be some radiation effect. Of the total fatalities, some 50 percent were a result of radiation factors.

Now, by assuming a 50-percent effective evacuation of the target areas——

Representative HOLIFIELD. At that point I think you should tell us where you have your evacuation centers.

Mr. SHAFER. On this first analysis, in which there were about 82 million fatalities, there was no evacuation assumed, simply a duck-and-cover operation upon the sound of the warning bell that an attack was imminent.

Representative HOLIFIELD. All right. Now, you are going to assume evacuation. Where are you going to evacuate them to, under the same conditions, to protect them from fallout on a map of that type?

Mr. SHAFER. We had to make two assumptions on this particular phase of the analysis.

Assuming a 50 percent of effective evacuation beyond the D zone ot blast damage, that would be from 5 to 15 miles beyond ground zero, depending on weapon size; assuming a 50-percent effective evacuation, and assuming the existence of a radiation shelter program in the United States, assuming the existence of shelters to which evacuees could go, the fatalities decreased to about 31 million. So there was a net saving of over 50 million people under a radiation shelter program, and an assumption of 50 percent effective evacuation beyond the primary effects of the weapon.

Senator PASTORE. And that hypothesis is predicated upon an attack of 2,500 megatons within a period of 2 hours, and you are talking about evacuees within that period?

Mr. SHAFER. The evacuation immediately prior to that, sir. Evacuation beyond the D zone of blast damage. Evacuation for, perhaps 5 to 15 miles to shelters prior to the attack, perhaps 1 hour, or perhaps less than 1 hour prior to the attack.

Representative HOLIFIELD. Of course, you have not only made two assumptions which cannot obtain under present conditions, one, because you do not have a warning time; two, because you do not have a shelter system; but you made a third assumption that you know where point zero of the falling bombs is going to be. All three of those assumptions are in the realm of impossible prediction.

Mr. SHAFER. Actually, in the analysis, we only assumed a 50-percent evacuation of the target areas attacked in this particular exercise; that is correct.

Representative VAN ZANDT. Mr. Chairman?

Representative HOLIFIELD. Mr. Van Zandt.

Representative VAN ZANDT. In 2 hours' time how many bombs were dropped.

Mr. SHAFER. 250 bombs on 144 areas.

Representative VAN ZANDT. 144 areas?

Mr. SHAFER. That is right.

Representative VAN ZANDT. Your chart indicates that they dropped bombs on the Northwest?

Mr. SHAFER. That is correct, sir. Seattle——

Representative VAN ZANDT. And California?

Mr. SHAFER. Correct.

Representative VAN ZANDT. And then moved east. How about Arizona and New Mexico?

Mr. SHAFER. Yes, sir. We have weapons detonated at Phoenix, at some of the airbases near there, and at Tucson.

Representative VAN ZANDT. How about the Salt Lake City and Denver areas?

Mr. SHAFER. That is correct, sir. Hill field in Utah, and also Salt Lake City itself, sir. And Denver, at the airbase outside of Denver, and Denver city itself.

Representative VAN ZANDT. In other words, you covered all the densities of population in the United States?

Mr. SHAFER. Many of them, that is correct.

Representative VAN ZANDT. Whether military or otherwise?

Mr. SHAFER. Military, civilian, and industrial targets were the primary objectives. However, there are some random detonations also at areas that would not meet those criteria.

Representative VAN ZANDT. You said 50 percent of the casualties could be charged to radiation?

Mr. SHAFER. That is correct.

Representative VAN ZANDT. Are we to assume the other 50 percent were killed by blast effect?

Mr. SHAFER. That is correct, blast and thermal effect.

Representative PRICE. Mr. Chairman?

Representative HOLIFIELD. Mr. Price.

Representative PRICE. What type of bombs were you assuming?

Mr. SHAFER. Thermonuclear-type weapons, and obviously they were not the relatively clean type of which you were speaking yesterday.

Representative PRICE. Exclusively H-bombs?

Mr. SHAFER. That is correct.

Representative VAN ZANDT. In your imagination, did you provide for an aerial burst?

Mr. SHAFER. These are all surface detonations.

Representative VAN ZANDT. All surface detonations?

Mr. SHAFER. Yes. You will notice there is quite a variation of the pattern since we used the actual existing meteorology of a particular day.

For example, in Florida the winds were much less strong, than over here [indicating], say across Colorado and across the northern plains. As I recall the wind speeds in the Florida peninsula were in the matter of the neighborhood of perhaps 15 miles per hour, the mean effective wind from 80,000 feet to the surface, whereas they exceeded 50 miles per hour as we went further north.

Representative VAN ZANDT. What period of time did the deaths occur?

Mr. SHAFER. The first 60 days. Our computations went for the first 60 days, sir. There may have been some deaths beyond then, because, as pointed out yesterday, the delivery of radiation exceeds 60 days. However, certainly the bulk of the problem would be indicated.

In this particular exercise we dealt only with the immediate survival problem. We did not take into account the soil contamination, the uptake of strontium 90, and the long-term haul problem that certainly would be very much with us from an attack of this magnitude.

Chairman DURHAM. How about water? Did you take that into consideration?

Mr. SHAFER. No, we did not take contamination of water into account here. Certainly there would be considerable contamination of reservoirs from fallout, from rainfall, moving the deposition from its point of contact and into reservoirs.

Representative HOLIFIELD. You might say, then, this represents the immediate effect, say, the within-24-hour effect?

Mr. SHAFER. As far as this analysis of the fallout is concerned; yes. The mortality of fatality statistics which I gave you indicated the first 60 days.

Representative HOLIFIELD. Yes.

Mr. SHAFER. As far as contamination of water is concerned, certainly southern Lake Michigan would have had a considerable amount from this. Many cities depend upon their drinking water from Lake Michigan.

Senator PASTORE. It is my prayer that these questions always remain hypothetical, but why did you take the figure of 2,500 megatons?

Mr. SHAFER. Solely to study the problems connected with a large-scale attack with ground-burst weapons. There is nothing significant about the figure 2,500. This is one of an infinite number of attacks which could have been assumed. I might advise the committee that we have studied attacks with much less and much greater megatonnage than this. We recently completed an agency exercise based upon a 20-megaton surface detonation on all of the 314 targets in the United States. The megatonnage was some 2½ times that indicated on this analysis, but it was very specialized. It was certainly a situation that no enemy would be able to accomplish, to get 314 intended weapons upon their intended targets.

Representative HOLIFIELD. This, of course, does not give us an estimate of the amount of radiation that would go into the world's atmosphere and stratosphere, and which would fall over the following 10 years around the world on areas which are not attacked by an immediate detonation of weapons?

Mr. SHAFER. That is correct, sir.

Chairman DURHAM. Then it was assumed in the preparation of the map that this could be accomplished in the 1960's?

Mr. SHAFER. This was not intended to represent capability at any particular time, although we assumed that such an attack could be increasingly within enemy capability during the 1960's.

Representative VAN ZANDT. Was it based on the Russian capabilities?

Mr. SHAFER. This was based solely upon our assumption for this exercise.

Representative VAN ZANDT. Was it based upon Russia's capability of getting 100 percent of her planes through to the target?

Mr. SHAFER. No, sir. We assumed that this represented those aircraft which were able to penetrate our borders and deliver their weapons, 250 weapons. I do not know how many aircraft that would require. If the Air Defense Command were effective in knocking down 50 percent of the invading bomber aircraft, this would imply 500, perhaps, in the original attack.

Representative VAN ZANDT. Would you take a bomb burst over Los Angels, and trace it as it moves east, giving us some idea of the destruction in human lives?

Mr. SHAFER. That would be rather difficult, but I will attempt it, sir.

There were four weapon detonations in the vicinity of Los Angeles, the large area, the large population center, the country. The blue-dashed line at the end of my pointer represents the area which would be affected by fallout at the end of 1 hour. That is 1 hour subsequent to the detonation. The levels in the yellow area would exceed 3,000 roentgens per hour. Unless survivors in that area had very good shelter, shelter with a shielding factor of perhaps 5,000, everyone would be dead. It would be a writeoff area.

Almost the same generalization in the red area. Not so much in the blue. Certainly not in the green. And when we get out to the white, a relatively no-hazards area at all.

By the end of 3 hours, the debris would have moved down almost to the extreme southeastern portion of California, almost to the Colorado River, the border between Arizona and California. By 7 hours, it would be over to central Arizona. However, at this time you would have to decrease the levels of radiation indicated on here by a factor of 10, as was mentioned yesterday, the radiological decay, the radiation decay which takes place. So by this time, in the yellow areas the dose rates are no longer 3,000 r per hour, but are down to 300 r per hour. In such a field as that, one could still be exposed to a lethal dose in less than 2 hours' time.

The debris spread on eastward to New Mexico by about 12 hours. However, by this time there have been considerable overlaps from attacks on San Diego, and from attacks on Arizona; so it becomes rather impossible to trace the debris from one single bomb.

Here is one [indicating] in the data which can be traced a bit more easily. This represents 6 hours of time; some 12 hours down to Grand Canyon; 18 hours, perhaps, over to the Colorado border; and by 24 hours into the Denver area. But it would be of no significance at Denver, since Denver has been struck by 3 weapons some 24 hours before, and the addition at this time is a relatively no additional value. Is that what you wanted, sir?

Representative VAN ZANDT. That is it; thank you.

Representative HOLIFIELD. Mr. Shafer, will you please give us your background, whom you work for, and so forth, so we can have that on the record?

Mr. SHAFER. Yes, sir. I am a meteorologist from the United States Weather Bureau. I have been assigned to FCDA, the Federal Civil Defense Administration, for the past 2 years, to assist them in their radiological defense problem.

Representative HOLIFIELD. How long have you been in this work?

Mr. SHAFER. In the Weather Bureau?

Representative HOLIFIELD. Yes.

Mr. SHAFER. I have been in the Weather Bureau 16 years, sir.

Representative HOLIFIELD. In presenting this, do you feel that this is supported by a majority of the meteorologists; that this sort of a hypothetical portrayal would be supported by most of them?

Mr. SHAFER. Most of them would not take strong exception to this. As indicated yesterday, there are 4 different techniques, or ways of

doing this, and each of the 4 yields some minor variation. As far as presenting the magnitude of the problem, and, for planning purposes, to indicate what we are up against, this is reasonably accurate. For actual operations in the event of an attack, for actual survival operations, this would not be adequate. We could only accomplish an analysis such as this by complete monitoring or by a combination of monitoring and meteorological techniques.

Representative HOLIFIELD. Are there any further questions?

Thank you very much, Mr. Shafer.

Mr. SHAFER. Thank you, sir.

Representative HOLIFIELD. Dr. Kellogg.

Dr. KELLOGG. Are there more questions about this?

Representative HOLIFIELD. I think we will not need the charts.

Dr. KELLOGG. This closes my presentation. The analysis by Mr. Shafer was the last thing I wanted to present to the committee.

Representative HOLIFIELD. All right. Before you leave the stand, as an experienced student in this field, would you have anything to add to this presentation of Mr. Shafer on this particular point?

Dr. KELLOGG. No; I think he covered it very well.

Representative HOLIFIELD. From your scientific background and professional standing, would you concur, in general, with the remarks that he made?

Dr. KELLOGG. Yes. The techniques which he used are, I think, fairly well accepted by those of us who are planning fallout calculations.

Representative HOLIFIELD. Are there further questions of Dr. Kellogg?

Thank you very much, Dr. Kellogg, for your appearance before the committee. Your testimony has been very valuable.

Our next witness will be Dr. Lester Machta, of the United States Weather Bureau, and he will continue the testimony on atmospheric transport, storage, and removal of particulate radioactivity.

Dr. Machta has previously testified before congressional committees, and is looked upon as one of the real experts in this field.

STATEMENT OF DR. LESTER MACHTA, METEOROLOGIST, UNITED STATES WEATHER BUREAU [2]

Dr. MACHTA. Thank you, Mr. Chairman. I thank you for the opportunity of continuing the meteorological presentation. The story which I would like to tell pertains to a meteorological prediction of global fallout, and how this is verified by actual observation, and, finally, what this may mean for us in the future.

The radioactive debris which has not fallen out locally is carried by the atmosphere to distances far removed from the point of the

[2] Meteorologist, U. S. Weather Bureau; associated with atomic energy and meteorology since coming to Washington in 1948, now Chief of the Special Projects Section. Born in New York, N. Y., in 1919, graduated cum laude from Brooklyn College in 1939. His meteorological training includes graduate work at New York University (master of arts, 1946) and at Massachusetts Institute of Technology (doctor of science, 1948). During the war he taught meteorology in both a civilian and military capacity for the Air Force. Member of Sigma Xi, Pi Mu Epsilon, the American Meteorological Society, and the American Geophysical Society. Recently been given a gold medal for exceptional service by the Department of Commerce. Publications in the meteorological literature are numerous and, in recent times, include papers on atomic energy and meteorology. Has been a member of many important Government committees, including the Advisory Committee passing on the meteorological safety of tests in Nevada. Has been instrumental in making the worldwide measurement of radioactivity part of the International Geophysical Year program. (Submitted by U. S. Department of Commerce.)

explosion before entering man's environment or body. Why are we interested in the details of this transport? Aside from the academic meteorological implications, there are at least two aspects of atmospheric transport which are of importance to these hearings.

First, if the radioactive debris remains suspended sufficiently long, radioactive decay can reduce the hazard of the particles. Unfortunately, evidence points to residence times in the atmosphere which are too short to allow for appreciable decay of such substances as strontium 90 and cesium 137 with their 27- or 28-year half lives. Second, and more important, is the question of the uniformity or nonuniformity of deposition over the earth. We will return to this point later.

Senator BRICKER. Is the half life of cesium 137 practically the same as strontium 90?

Dr. MACHTA. I believe so, sir. The radioactive debris which has not fallen out locally can be carried either by tropospheric or stratospheric winds. I should like to show a number of placards.

The first placard (1) shows the earth as a sphere bounded by a layer of air in which our weather takes place, known as the troposphere; the upper layer, which is separated from the troposphere by the tropopause shown here as the line, is the stratosphere. The break in the tropopause in the area in which J appears is believed to be frequently associated with the jet stream, a current of high-speed west-to-east winds. The everyday weather—cloudiness, precipitation—occurs only in the troposphere. We are well informed about the tropospheric air motions, but know much less about the stratospheric air motions. Two features are, perhaps, of importance. First, there is considerable turbulence and, hence, mixing in the troposphere. On the other hand, the stratosphere is rather smooth and, as far as we know, much less vertical mixing takes place there.

Second, in both the troposphere and stratosphere, the prevailing winds blow from west to east or from east to west, so that the transport occurs much more rapidly in an east-west or west-east than in a north-south direction.

The fate of the radioactivity that is left over after local fallout has ceased depends upon whether it has been left behind in the troposphere or forced into the stratosphere. Thus, as has been mentioned many times, high-yield explosions with their tremendous force throw the mushroom heads into the stratosphere, while the lower yield tests such as we conduct in Nevada remain in the troposphere. High air bursts of almost any yield can throw their debris into the stratosphere, also.

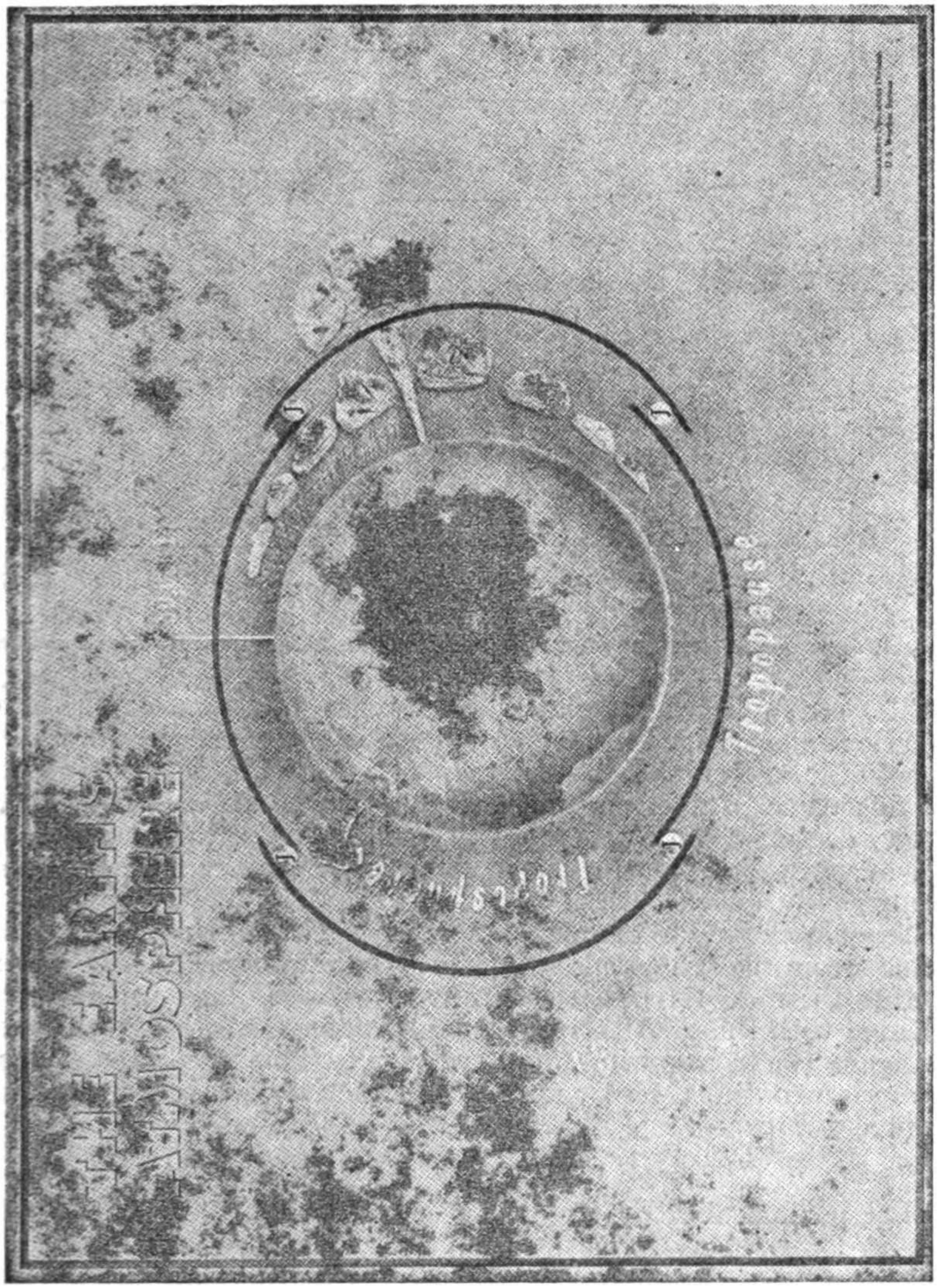
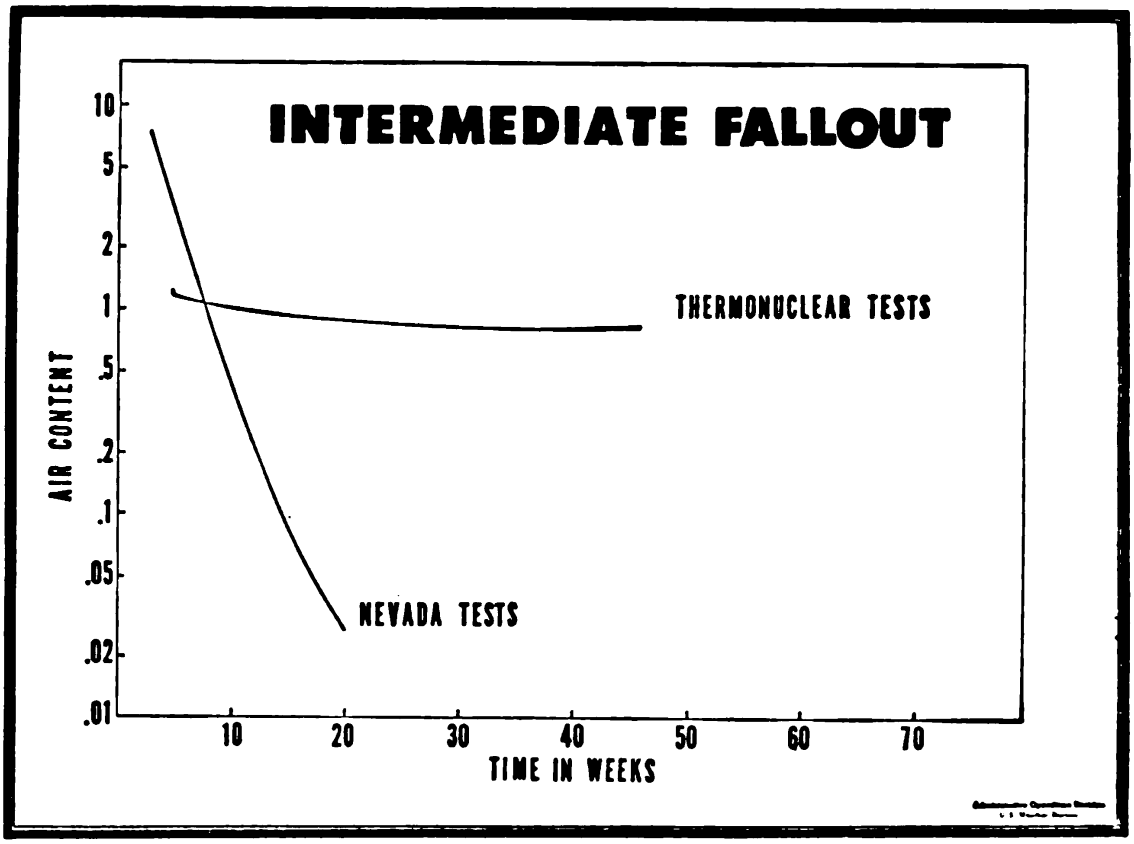


FIGURE 1

FIGURE 2



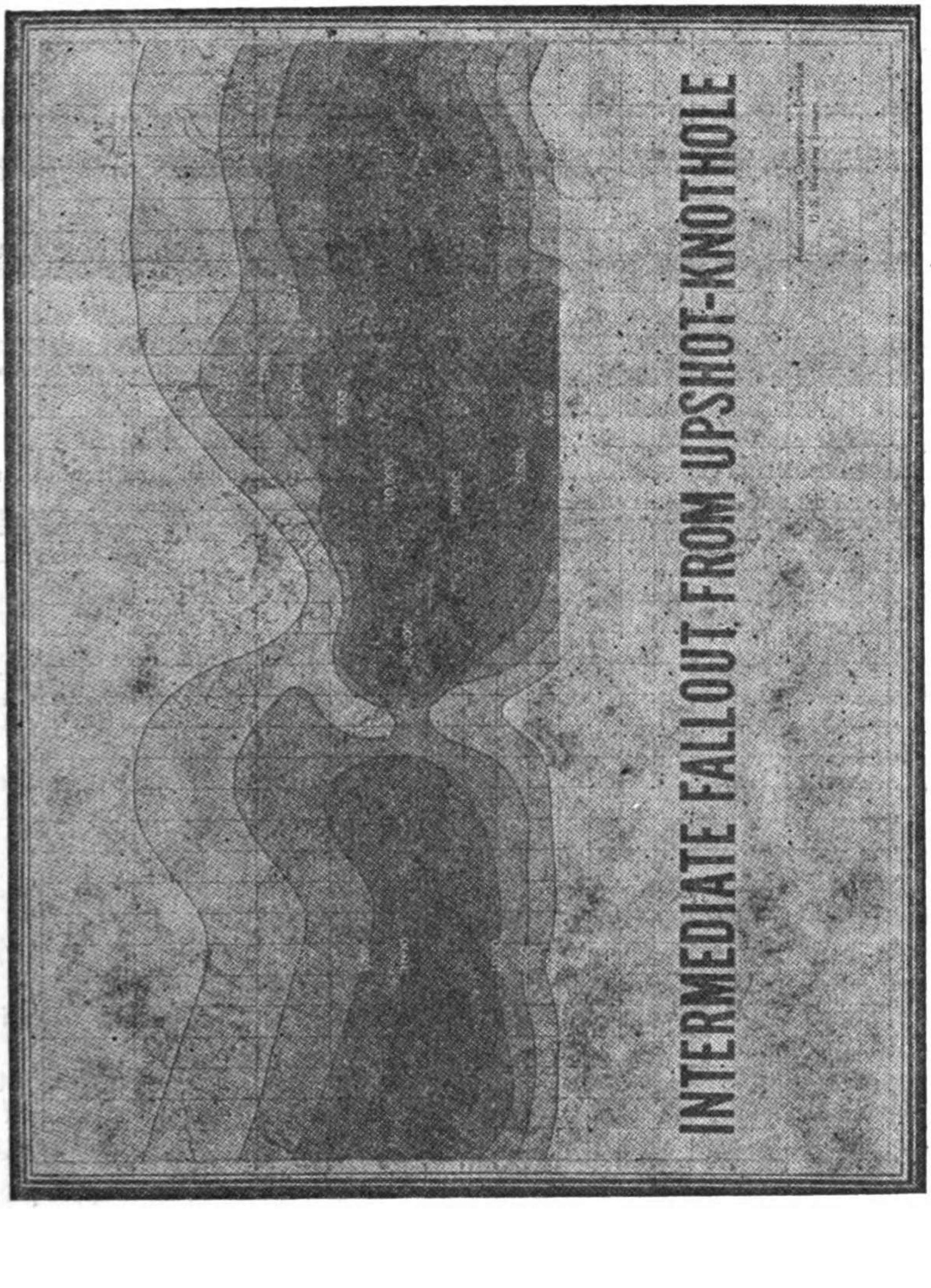
The next placard (2) shows the decrease with time of the atmospheric radioactivity from tropospheric and stratospheric sources. We see that for a Nevada A-bomb-type shot, in which air content is plotted against time in weeks after the explosion, the atmospheric radioactivity decreases rapidly with time after the test, so that within a matter of weeks, or at most a few months, the level of radioactivity is not appreciably above natural backgrounds. Precipitation and turbulence quickly remove the particles from the atmosphere. On the other hand, from the large-scale explosions, the thermonuclear tests, which throw their debris into the stratosphere, one finds practically no change with time. Although the same processes of removal are still active in the troposphere, the curve fails to show the decrease because there is a continual feeding of new radioactive debris from the stratosphere downward.

TROPOSPHERIC FALLOUT

Let us first look at the fallout from tropospheric debris. This placard (3) shows isolines of deposition from one of the Nevada test series. It is a Mercator map of the entire world, and the very heavy shading indicates the area around Nevada.

The brightness of the red coloring is proportional to the amount of fallout. I use the word "tropospheric" and "intermediate" interchangeably in this discussion. This picture illustrates the prevailing west-east flow by the fact that most of the radioactivity lies in the same belt of latitude as the original latitude of the explosion. The fallout is carried primarily to the east by the prevailing winds, and decreases in intensity as we get farther from the test site.

FIGURE 8



Representative HOLIFIELD. Before we leave that, Dr. Machta, I want to reread one of the lines you have given.

Dr. MACHTA. Yes, sir.

Representative HOLIFIELD (reading):

This picture illustrates the prevailing west-east flow by the fact that most of the radioactivity lies in the same belt of latitude as the original latitude of the explosion.

Judging from the shading on your map there, and from this statement, then, there is a deposition in the Temperate Zone, assuming that is where these tests occur, where most of the people live, which is higher in intensity, although in different gradations, than it would be in either of the polar zones?

Dr. MACHTA. That is exactly correct, sir.

Representative HOLIFIELD. So when we talk about average global fallout, although it is a theoretical equation, it is an unreal evaluation in terms of the phenomena which actually occur?

Dr. MACHTA. I would like to take this up later. My main presentation actually deals with the nonuniformity of the fallout, and this is one of the aspects which gives rise to nonuniformity, namely, that the tropospheric fallout remains in the same latitude belt that the explosion takes place. But this is only one of the aspects.

Representative HOLIFIELD. My observation is, although it is only one of the aspects—my observation still is——

Dr. MACHTA. Is correct.

Representative HOLIFIELD. Is correct?

Dr. MACHTA. Yes, sir.

Representative HOLIFIELD. Thank you.

Dr. MACHTA. The next placard (4) provides the tropospheric fallout, the cumulative deposition for the first 35 days from the Castle-Bravo, the March 1, 1954, thermonuclear detonation in the Marshall Islands, showing once again that the fallout lies largely in the belt of latitude in which the explosion takes place. In the case of the large explosions, it is likely that the stem of the nuclear cloud provides most of the radioactive fallout in this period.

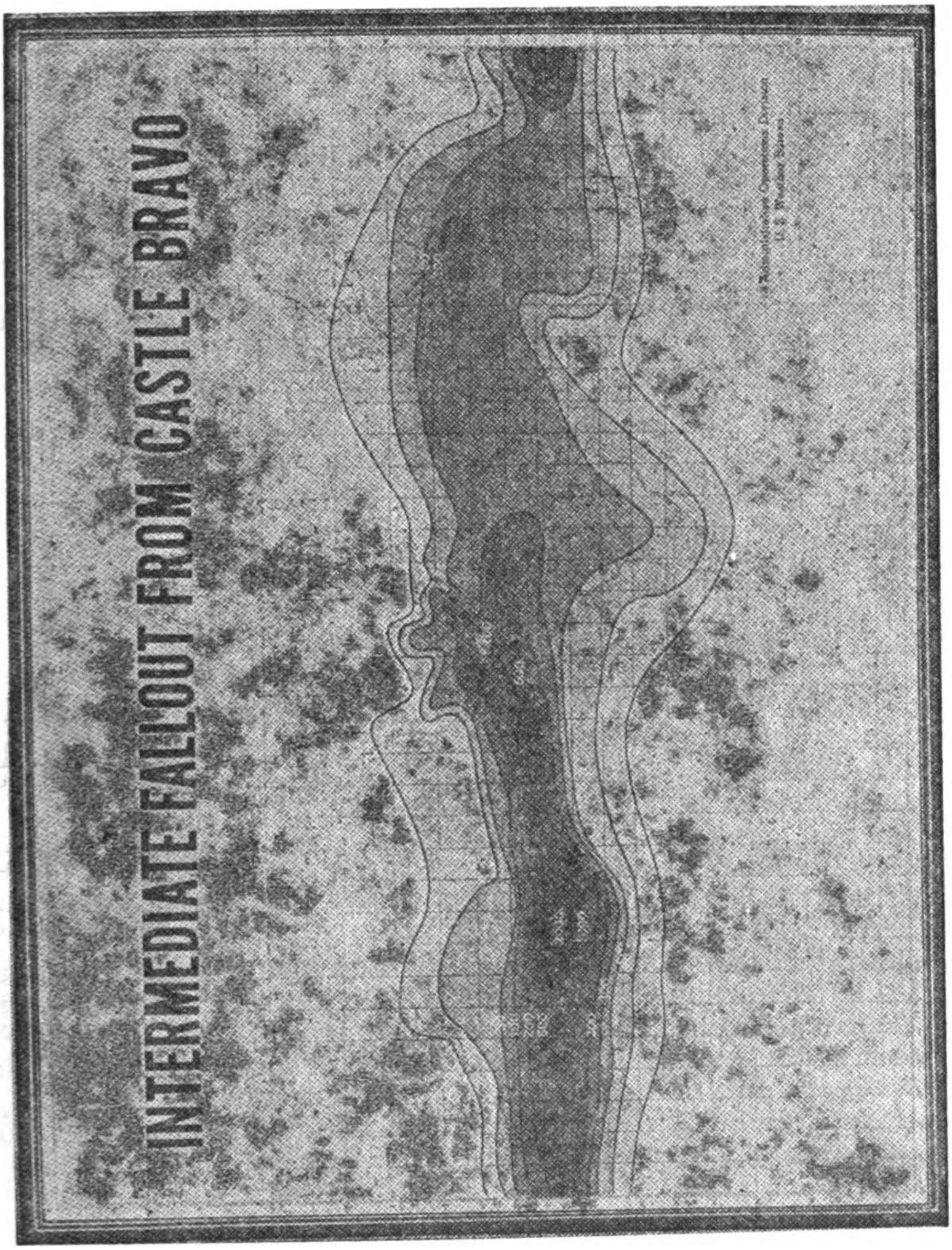
What fraction of the radioactive debris is deposited in the first few weeks or months—aside from the local fallout? For the typical Nevada tower shot, perhaps 75 percent, and for the high-yield ground explosion in the Pacific Proving Grounds, somewhere between 1 and 5 percent. These figures are very uncertain. Thus for the high-yield explosions, the delayed fallout is more important than the tropospheric fallout. This is because about 80 percent falls out locally, and when we add to this 5 percent more, we still have of the order of 15 to 20 percent, on the average, in stratospheric fallout that is still left after local and tropospheric fallout has ceased.

Thus, for the high-yield explosions, the delayed fallout is more important than the tropospheric fallout. It is evident that the tropospheric fallout is not uniform over the globe, as you just pointed out, sir.

STRATOSPHERIC FALLOUT

Finally, those particles which do not fall out locally or in the first 1 or 2 months, remain suspended in the atmosphere for a prolonged period—a matter of years, on the average. This has been termed

FIGURE 4



delayed or stratospheric fallout. These particles originate exclusively in the stratosphere. We do not know their size. The only thing we can say is that they must be quite small in order to remain airborne for such long periods of time. However, whether they are only carried downward from stratosphere to the troposphere by air motions or whether they also sink due to their weight, is not yet known for sure. From evidence I have seen, I would gues that there is a slow settling of the particles as fast as a mile or so per year—the principal removal is by downward atmospheric motions.

The radioactivity which is inserted into the stratosphere can be transported by 1 or 2 atmospheric processes; first, mixing, and second, direct transport. To understand these, consider an analogy—how a blob of ink in a bathtub can be transported, where the bathtub is considered to be the stratosphere. In mixing, one can imagine that the bathtub is stirred so that the ink quickly covers the entire water of the bathtub. In the second way, direct transport, one may imagine that a cup is dipped into the bathtub and part or all of the blob of ink is bodily lifted from one part and inserted into another part of the tub. It is quite evident that the first process, mixing, tends toward uniformity, whereas the second simply transports a blob from one place to another without materially changing the concentration. Our knowledge of the stratosphere is too limited to be sure of the comparative importance of these two processes. We are fairly sure that the vertical mixing—the exchange in the vertical—is very slow in the stratosphere due to the smoothness of the airflow.

I believe that the main movement of radioactive particles in the stratosphere is the result of direct transport. Mixing is so slow that the stratospheric distribution is nonuniform, even after 2 years.

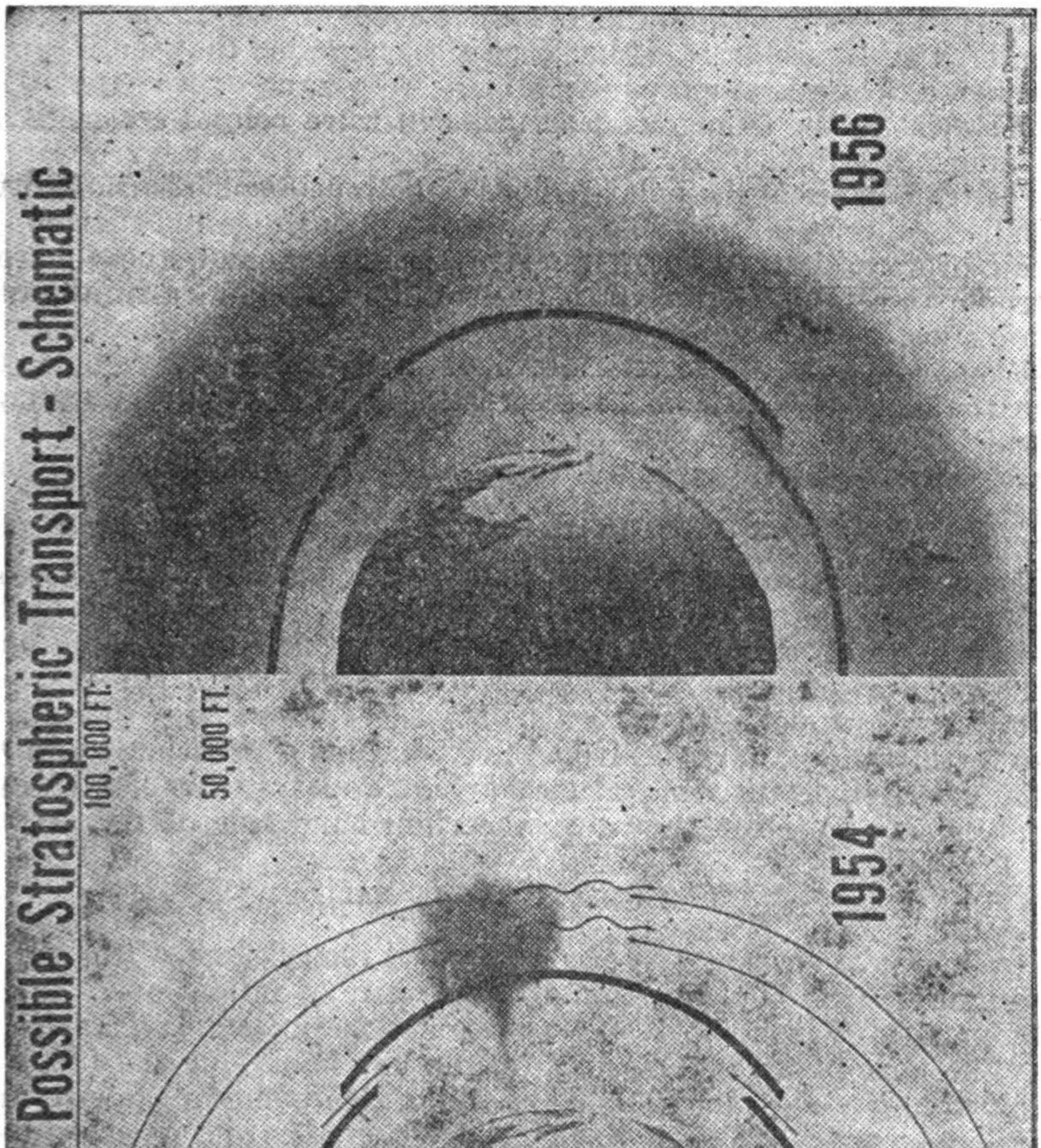
There are several meteorological hypotheses of direct transport or circulation in the stratosphere. I believe that a recent one proposed by Dr. Brewer of England best fits the facts available to me. Brewer is referred to as having said that there is—

> * * * slow poleward circulation of stratospheric air from the equatorial regions. During the course of this circulation, the air may be carried to heights of the order of 30 kilometers—100,000 feet—the height being greater in the winter hemisphere * * *.

The next placard (5) will show my interpretation of this circulation on the left-hand side. We see half of the globe and the tropopause as in earlier pictures. The H-bomb nuclear clouds in the Marshall Islands at 11° north, are shown schematically as one large red cloud. The wiggly arrows pointing southward indicate the possibility of southward mixing of a small part of the initial nuclear clouds into the Southern Hemisphere. In each hemisphere, we see the slow poleward circulation proposed by Brewer. I conclude that the bulk of the radioactivity in the stratosphere as in the Northern Hemisphere as illustrated on the right-hand side of the placard (5) by the heavy shading. The uncertainty in Southern Hemisphere stratospheric content is reflected by the question marks. I also believe that the bulk of debris is in the northern portions of the Northern Hemisphere rather than uniformly spread throughout the hemisphere.

Having now transported our radioactive debris to a different part of the stratosphere, let us ask where and how the debris may leave the stratosphere to enter the troposphere. Here, again, we have a

FIGURE 5


Possible Stratospheric Transport - Schematic
100,000 FT.
50,000 FT.
1954
1956

number of theories but no positive direct evidence. Ordinary vertical mixing processes will remove debris from the stratosphere through the tropopause and into the troposphere at all latitudes. However, it is believed that the break in the tropopause which one frequently finds in the vicinity of the jet stream, the region of very high west to east speeds in the temperate latitudes of both hemispheres, is a place of preferential exchange of air between troposphere and stratosphere. It is possible that it is in this area that much of the radioactive debris enters the troposphere. It has been also suggested that the formation of new and higher tropospauses, which may also occur with the passage of storms in the temperate latitude, will leave behind a considerable amount of stratospheric air to be incorporated into the troposphere. The tropopause of the polar regions of both hemispheres is often very indistinct, especially in winter and it has been suggested that removal can preferentially occur here. On the other hand, the equatorial tropopause is noted for its persistent intensity and a minimum of transport may occur through it. Meteorological theories, therefore, recommend more stratospheric removal in the temperate or polar than in the equatorial regions of the earth. The lengths of the arrows, which you see on the left-hand side of the placard (5) across the tropopause and through the tropopause break suggest the relative removal rates.

Once radioactive particles enter the troposphere, their stay is short. The ordinary weather processes and settling out of particles removes them from the atmosphere in a matter of weeks or a few months, according to best opinions. On the next placard (6), we see some of the removal processes. Impact on vertical surfaces, such as trees or forests, on grasses of wheatfields, on sides of houses, side of hills, and so forth, removes particles from the troposphere. Further, and by far the most important removal mechanism, appears to be scavening by falling precipitation shown on the right-hand side of the drawing.

THE UNIFORMITY OF FALLOUT

With these introductory meteorological remarks out of the way, let us now return to our question of uniformity of fallout over the globe by particles which are part of the stratospheric or delayed fallout.

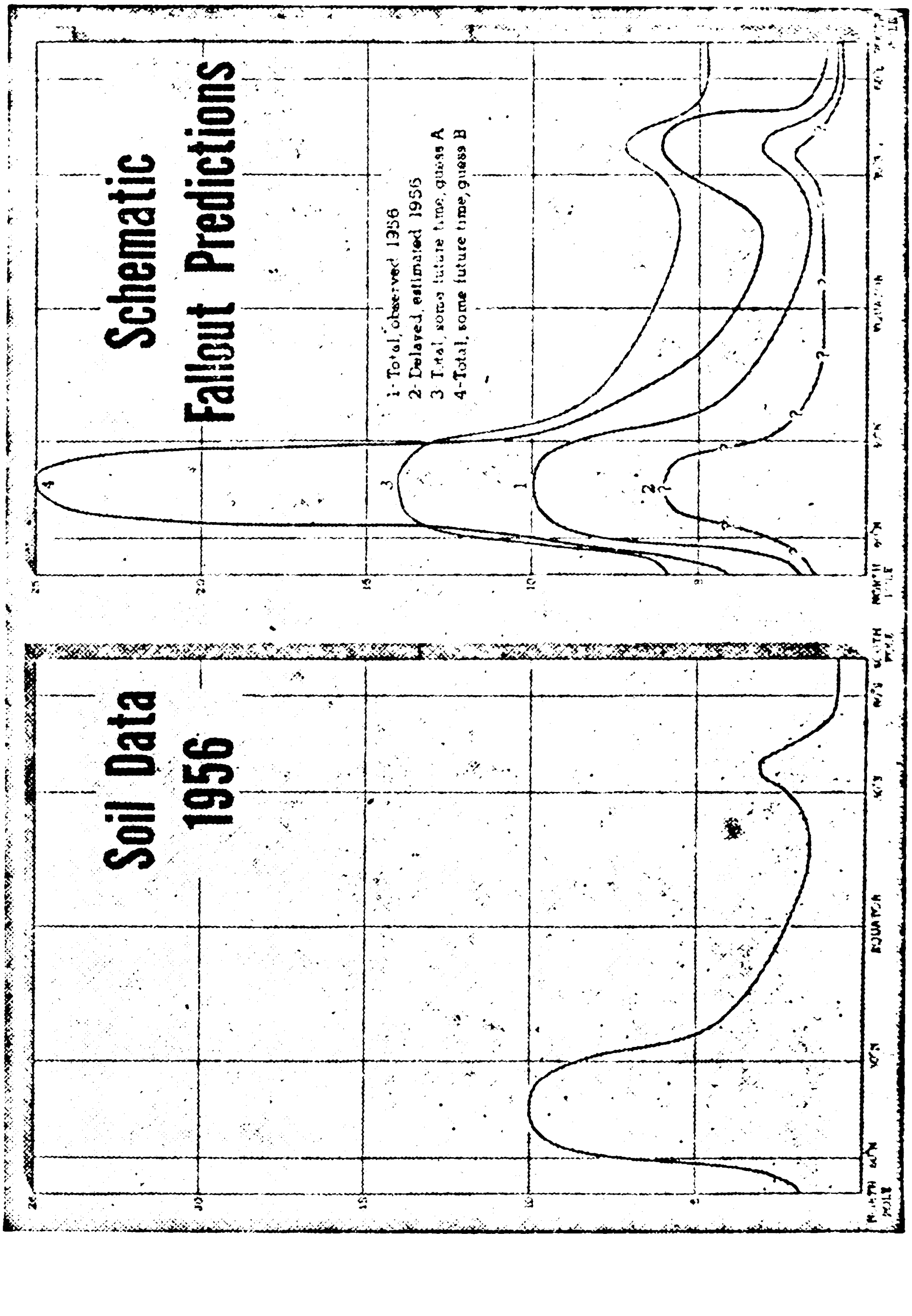
The next placard (7) shows on the left hand side the individual soil sample strontium 90—that is the ordinate shows the amount of fallout—fallout values plotted against latitude from pole to pole, as of 1956. That is, we have a sample from one place with a certain latitude, having a given value, and it appears at the point on the graph which you see in front of you. The scatter of points is great, but the general sense of the points is given by the solid black line which is intended to represent a rough average latitudinal profile of strontium 90 fallout.

Mr. Eisenbud tomorrow will describe the limitations and uncertainties as well as the details of the soil sample results. The spread of points around the line reflects the peculiarities of atmospheric removal, that is areas of unusual rain or lack thereof, and idiosyncrasies of soil sampling and analyses which will be described later, by Mr. Eisenbud. One should view the picture broadly, since the uncertainty in individual values may be large.

FIGURE 6


REMOVAL PROCESSES
WIND DIRECTION
TREES
GRASS
WHEAT
BUILDINGS
DRIZZLE
RAIN & SNOW

FIGURE 7


Schematic
Fallout Predictions
1- Total, observed 1956
2- Delayed, estimated 1956
3 Total, some future time, guess A
4-Total, some future time, guess B
Soil Data
1956
EQUATOR

While this picture fits the meteorological description which I have just offered, namely greater fallout in the north temperature latitudes or between about 25° and 60° N., it would also fit a picture based on the assumption that the greater amount of fallout in the temperate latitudes of the Northern Hemisphere comes from our small Nevada and the small Russian tests. The peak coincides almost exactly with the latitudes of these tests. However, the evidence suggests that the bump is the result of preferred fallout from stratospheric sources as well as from the small Nevada and Russian tests.

Senator BRICKER. One question at that point, Doctor.

Dr. MACHTA. Yes, sir.

Senator BRICKER. I noticed in the public press it is generally believed that the recent rainfall in Washington which brought down some radioactive particles was from the Russian tests. Could you confirm that?

Dr. MACHTA. To the best of our knowledge, the debris remains suspended in the atmosphere for a period of months, and this reported fallout very well could have been the result of the Russian tests.

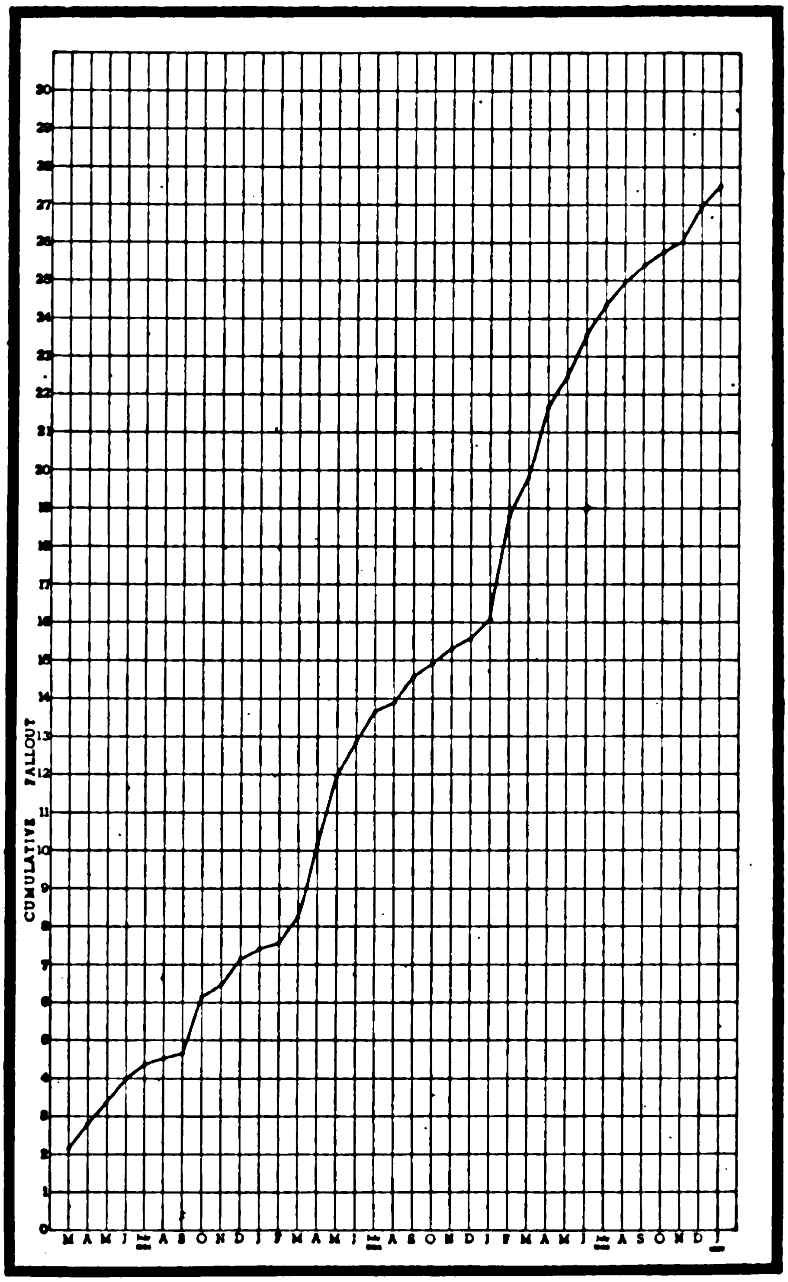
First, although the interpretation is uncertain, the magnitude of the bump calls for more fallout than could have been produced by our Nevada and the smaller Russian tests which have occurred up to the time at which this drawing is applicable. Second, we have a measure of the contribution of tropospheric fallout alone in the United States. In the fall of 1953, strontium 90 fallout was about 5 units compared with 25 or 30 units in the fall of 1956. By 1953, we had conducted 31 of 45 Nevada tests, several Pacific tests series nad the U. S. S. R. had detonated a number of nuclear bombs. The tropospheric fallout since 1953, in my opiinon, could not account for the 20 or 25 additional units of fallout which occurred betwen 1953 and 1956, considering the Nevada and tropospheric Russian fallout.

This graph shows the cumulative amounts of fallout in the vertical plotted against time in months along the horizontal, and shows how in New York City the strontium 90 fallout has been building up with time.

For a third argument, the curve of fallout versus time derived from collections by an exposed pot in New York City is shown in the next placard (8). The changes in slope at various times are evident. It has been suggested that the gentle slope is due to continual drip from the stratosphere and the cliffs due to the additional temporary tropospheric fallout.

Although this thesis is questionable, since the steep rises might be due to more rain at the time, and small tests were held in the U. S. S. R. during the periods of gentle slopes, one can get an idea of the ratio of tropospheric to delayed fallout using this concept. The gentle slope times the period of record yields the stratospheric fallout. The result is that about 50 percent of New York City fallout or 14 units is delayed and 50 percent tropospheric. Finally, in the case of rainwater collections at New York, shown on the same placard (8), it has been possible to analyze for a radioisotope of a short half-life from which a separation of young tropospheric and old stratospheric debris can be made. We find that most of this fallout must be attributed to delayed fallout. Unfortunately, the only radioisotope available,

FIGURE 8



New York City Pot Data

strontium 89, which has only about a 60-day half-life, is not measured as accurately as we would desire.

I have belabored this point because, in the final analysis, the evidence for nonuniform stratospheric deposition should come from fallout data itself and not from meteorological theories. I believe the evidence to be strong enough to indicate nonuniform delayed fallout, so that in future calculations, it should be taken into account. For example, consider the right hand side of the placard (7). The black solid line labeled (1) is a direct copy of the rough latitude profile shown on the left hand side. This is what we see on the ground from all sources in 1956 as best as I can interpret between the points.

The dashed black line (2), below the observed curve, is an estimate, little more than speculation, of the distribution of stratospheric fall-

out up to 1956. The difference between the dashed line and the solid line is what the Nevada tests, the smaller Pacific and the smaller Russian tests have contributed. The lower curve is what has dripped out of the stratosphere. The bump in the north temperate latitude is not as pronounced in the stratospheric fallout curve.

Two cases are now considered. The same amount of fallout has been added to the 1956 observed curve in both cases, an amount of stratospheric fallout about equal to the total already deposited. That is the amount given by the curve on the left, or from all sources. This is not to be construed as indicating that this is necessarily the amount yet to be deposited, but rather it is used for illustrative purposes only. The green curve labeled (3) shows a future profile if the same amount of fallout is added at all latitudes. This is the case of adding everything uniformly to the earth. The red curve (4) with the much more marked peak, shows a profile with pronounced nonuniform future fallout, as I would envisage it. The ratio of the peak value of the nonuniform to the uniform curves is almost 2; the nonuniform peak is about 3 times the world average.

Representative HOLIFIELD. If your theory is right on that, then this would have a direct effect upon the tolerance levels which we are talking about from a worldwide standpoint?

Dr. MACHTA. I am afraid I am not competent to talk about tolerance levels, only about meteorology.

Representative HOLIFIELD. It would more than double, then, the previous estimate as to contamination, would it not?

Dr. MACHTA. May I continue to give my viewpoint on what this actually does in the next paragraph?

Representative HOLIFIELD. All right.

Dr. MACHTA. In my view, these profiles represent the two extremes of distribution of future fallout if the present strontium 90 fallout is doubled. The true distribution should lie between the extremes.

I do not know, in fact, whether the upper curve is correct or the lower curve, but I think there is a possibility the upper one is correct, and we should say the truth lies between the two.

Representative HOLIFIELD. Is this an area where additional research is needed?

Dr. MACHTA. Yes; and I believe the AEC is conducting such research to try to pin this down.

Chairman DURHAM. How about your lower curve on the ground. That is correct, then?

Dr. MACHTA. I did not understand the question.

Chairman DURHAM. Your lower curve, is that accurate?

Dr. MACHTA. No. This is my speculation of what has come out of the stratosphere, too.

Chairman DURHAM. That is speculation too?

Dr. MACHTA. That is correct; and you may see it is estimated as of 1956.

There is one more additional calculation, and this is that nonuniform removal processes also result in nonuniform fallout patterns. Evidence suggests rainfall as being one of the major processes by which the particles are removed from the atmosphere. While agriculture occurs primarily in rainy areas, there are also rainy areas associated with the Icelandic and Aleutian low-pressure systems which

produce enormous amounts of rain over oceans and which are not associated with any agricultural areas. Thus, it appears as though the amount of rainfall in the milksheds and other agricultural areas of the temperate latitudes of the Northern Hemisphere contain very little more rainfall than the average rainfall in the latitude belt in which they exist. However, the rainfall and fallout relationship, is by no means perfect. It is my view, for example, that air masses in which rain has just begun produce more fallout than the air which has not been cleaned by previous rain.

SUMMARY

In summary, I would like to list our knowledge with regard to pertinent meteorology and the uniformity of fallout.

These facts are quite certain, and everyone agrees to them:

1. Much of the long-lived radioactive debris from high-yield tests remains airborne in the stratosphere for years, not weeks or months.

2. Tropspheric fallout lies mainly in the band of latitude of the test and is, therefore, not uniformly spread over the earth.

3. The observed soil data in 1956 reveals nonuniform strontium 90 fallout over the globe. On the average, there is more fallout in the north temperate latitudes.

These points can be presented with varying degrees of confidence:

1. After 2 years, debris in the stratosphere from our Castle test is still not uniformly distributed in the stratosphere. The upper air program of the Atomic Energy Commission can check this thesis in the near future.

2. The stratospheric removal rate and the stratospheric distribution of radioactivity with time depends on the latitude and height of the injection. For example, a contaminant introduced just above the tropopause at 50,000 feet mean sea level at, say, 45° north will come out of the stratosphere much more quickly and in a less dilute form on the ground in the temperate latitude than injections in the Marshall Islands at, say, 80,000 feet. In other words, where and when it will come out depends on where you put it in.

3. Delayed fallout has not been deposited uniformly over the earth. On the average, there is more delayed fallout in the north temperate latitude, even though the main injection was in the Tropics, that is the Marshall Islands.

Finally, we know comparatively little about these points and the conclusions are speculative:

1. The degree of nonuniformity of delayed fallout to date or in the future is unknown. One can put reasonable bounds on the peak value in the temperate latitudes given the amount of delayed fallout.

2. I do not know whether there is also a preferential region of stratospheric fallout in the Temperature Zone of the Southern Hemisphere, but I suspect there might be.

3. The extreme local variability in fallout due to rainfall and other meteorological differences is not known for certain. I would guess that areas as large as milksheds, for example, would not have more than 2 or 3 times the average fallout for the latitude. On the other hand, the lack of rainfall and other removal processes can result in almost zero fallout.

Due to the uncertainty in defining the degree of uniformity, I would recommend that predictions of future fallout be assigned a range of

values based on the 2 extremes just described, in the belief the truth should be between the 2 of them.

Representative HOLIFIELD. Thank you very much, Dr. Machta for that very important presentation. Would you please remain for questions?

Are there any questions at this time of Dr. Machta?

Representative VAN ZANDT. Mr. Chairman?

Representative HOLIFIELD. Mr. VAN ZANDT.

Representative VAN ZANDT. Doctor, describe the jet stream to us. Is it spotty, or is it worldwide?

Dr. MACHTA. By and large the jet stream completely emcompasses the earth. There are areas in which the speeds are greater. However, it is not the jet stream, as such, which is of importance to us, we think. What is important are the places where there are breaks in the tropopause because it is in these areas where horizontal mixing can take materials from the stratosphere and bring them into the troposphere and not have to undergo vertical mixing.

Representative VAN ZANDT. Are they associated with seasons?

Dr. MACHTA. They are usually associated with the jet stream. In the wintertime in the United States, for example, they are located 25° or 30° north. In the summertime, they are much farther north along the United States-Canadian border. The altitude of the jet is about 35,000 feet, give or take a few thousand.

Representative VAN ZANDT. You have had experience with these tests in the Pacific, have you not, Doctor?

Dr. MACHTA. Some experience; yes.

Representative VAN ZANDT. Can you recall at any time immediately after the test when any phenomena developed at high altitudes, as far as weather is concerned?

Dr. MACHTA. In the very local area in which the tests took place, I think there may have been a few showers, which perhaps may not have otherwise occurred. They never extended more than a few tens of miles, I believe, from the area of the tests. I actually was not present at any of the Pacific tests.

Representative VAN ZANDT. On the other hand, other than showers, was there any development of extraordinary winds?

Dr. MACHTA. None to my knowledge, sir.

Representative VAN ZANDT. Some years ago, I think you were the coauthor of a paper that concerned a study made at the request of, I think, this committee regarding the effect of atomic tests on the weather. Would you comment on that paper at this time?

Dr. MACHTA. Well, the research which we have conducted since then does not lead us to believe that our conclusions were in any way erroneous. We still find no connection between the testing of nuclear weapons and the weather. We must admit we are still ignorant on a number of features, and there always exists a remote possibility that something we are not aware of does produce weather. We know of none such.

Representative VAN ZANDT. Doctor, if my memory serves me correctly, you said at that time, that, based on data available, we are simply passing through another cycle as far as world weather is concerned. Do you still hold this view?

Dr. MACHTA. I think the fact we have gone from a drought in the Texas area to what you now observe is sort of evidence there are cycles in the atmosphere.

Representative PRICE. Mr. Chairman?

Representative HOLIFIELD. Mr. Price?

Representative PRICE. Dr. Machta, you made a very interesting negative statement in here. I wonder if you would state it more positively. If you do, it seems to me it would be one of the most salient points of your statement, one of the most interesting points.

On page 10, under speculation No. 3, you say:

> I would guess that areas as large as milksheds, for example, would not have more than 2 or 3 times the average fallout for the latitude.

Stating that positively, you would say they have about 2 or 3 times as much?

Dr. MACHTA. I do not feel the data which are available would allow one to be positive that there are areas in which the fallout is necessarily 2 or 3 times as great.

In the United Kingdom, for example, the fallout readings in 1955 varied, I believe, from about 3.3 up to 10, and they found a very definite, positive correlation with rainfall. The value of 3.3 occurred in a dry area, and the value of 10 occurred in a rainy area. However, what the average should have been for the overall area is not certain.

Representative PRICE. Of course, these milkshed areas you are talking about are the areas where you pick up the most calcium, and where strontium 90 will do the most harm to the human race.

Dr. MACHTA. Yes. I do not think I used the word "milkshed" to indicate the rainfall is unusual in milksheds. I just wanted to indicate areas of that magnitude and size as having on the average not more than 2 or 3 times the total amount of rainfall for the general latitude band. I do not believe I can be any more specific than to indicate an upper bound.

Representative HOLIFIELD. Will the gentleman yield?

Representative PRICE. Yes.

Representative HOLIFIELD. The point of your testimony there is that, of necessity, a milkshed must be located in an area where there is enough rainfall for the production of hay and other material which the animals eat, and you relate that to the fact that rainfall does bring down stratospheric, at least tropospheric radioactive particles. It is upon that sequence of suppositions that you make the statement there would be more radioactivity in that area rather than in a desert-like area where there is no rainfall?

Dr. MACHTA. The data quite clearly prove that this is so. In Brawley, in the Imperial Valley Desert, the values are running much lower than they are for the rest of the United States.

Representative HOLIFIELD. That comes from scientific readings?

Dr. MACHTA. These really are actual measurements of the soil contents, sir, as reported by Dr. Libby and others.

Representative HOLIFIELD. Mr. Durham.

Chairman DURHAM. Dr. Machta, what you said here this morning not only applies to the United States, but has application worldwide?

Dr. MACHTA. This is entirely so, sir.

Representative HOLIFIELD. Do you have any evidence or information regarding the readings of fallout in Japan?

Dr. MACHTA. I would rather that this question be answered by Mr. Eisenbud tomorrow, since he is aware of the details and of the limitations of the data, sir.

Representative VAN ZANDT. Dr. Machta, at this point, may I inquire as to whether or not the information you gave us this morning, is in any way, shape, or form coordinated with the information that may have been passed on to you by foreign countries?

Dr. MACHTA. I believe that one of the points plotted here is taken from a published report from the United Kingdom. Mr. Eisenbud, again, is in a better position to advise you of the information in foreign countries than I am.

Representative HOLIFIELD. We will go into that in detail with him, then, if you prefer.

Dr. MACHTA. Yes.

Representative HOLIFIELD. Because there are several important questions in that area.

Dr. MACHTA. I think he would be much more competent in answering these.

Representative HOLIFIELD. Are there any further questions?

Senator BRICKER. Mr. Chairman?

Representative HOLIFIELD. Mr. Bricker.

Senator BRICKER. Doctor, there are scientists who disagree with you about the intermingling in the atmosphere and the uniformity of fallout over the world ultimately, are there not?

Dr. MACHTA. I am not aware of any that disagree. I may point out that we had a meeting a number of weeks ago with the Meteorology Panel of the National Academy of Sciences Committee on the Biological Effects of Atomic Radiation, at which we discussed this, and I believe that the tenor of conclusions raised by that committee is what I have presented in my paper. I am not aware of other meteorologists who would take exception to my statement.

Representative PRICE. Mr. Chairman?

Representative HOLIFIELD. Mr. Price.

Representative PRICE. Dr. Machta, how did you make this study?

Dr. MACHTA. You mean what led me to the conclusions indicated here?

Representative PRICE. Not only to the conclusions, what is your actual operation, the method of sampling?

Dr. MACHTA. Of sampling the earth?

Representative PRICE. Yes.

Dr. MACHTA. I believe again this is what Mr. Eisenbud will discuss tomorrow. He can verify and talk of the validity of the data. I am sorry. I have simply been given the information, and I am interpreting it in terms of meteorology.

Representative HOLIFIELD. In general, you can say it is from sampling of the soil in different areas of the earth's surface?

Dr. MACHTA. Yes.

Representative HOLIFIELD. And from atmospheric samples?

Dr. MACHTA. Yes, sir. This is in general what it is. The details can be presented later.

Senator PASTORE. Would you say the same as to your conclusion or speculation as to the gathering of this cloud in the Northern Hemisphere, that is, even from the shots that were at Marshall Islands?

Or do you know it is there up in the stratosphere, this deep concentration you talked about?

Dr. MACHTA. In the stratosphere?

Senator PASTORE. Yes. I mean, in your statement here, you rely a great deal on Dr. Brewer of England.

Dr. MACHTA. Yes.

Senator PASTORE. To what extent do you rely on him? What do you know of your own knowledge scientifically as to the existence of this contaminated material in the stratosphere in concentrated form in the Northern Hemisphere, even though the injection was in the tropical part of the earth?

Dr. MACHTA. The answer to this question, sir, is that I do have information which I have not presented to the committee, which is classified, and which leads me to believe it very strongly.

Senator PASTORE. I do not want to get into classification now. I want to get how much of this is speculation, and how much of it is facts.

Dr. MACHTA. The hypothesis of Dr. Brewer is speculation, sir. However, I do have other classified information which leads me to believe that the picture which he has drawn is in fact the truth.

Senator PASTORE. You mean predicated upon the fact that you know it is there?

Dr. MACHTA. Yes, sir.

Senator PASTORE. Then, insofar as Dr. Brewer is concerned, you are merely speculating as to what brings it there?

Dr. MACHTA. Correct, sir. He was offered the mechanism which accounts for the facts at my disposal. I try to proceed as a meteorologist would, sir.

Representative HOLIFIELD. As a layman, let me ask you this question: Is it not possible that we can obtain radioactive particulate from the stratosphere to sample?

Dr. MACHTA. This is already being done by the Atomic Energy Commission, sir.

Representative HOLIFIELD. So we are not speculating on what there is in the stratosphere. We know what there is in the stratosphere, as far as our samples indicate?

Dr. MACHTA. No, sir; I do not think the answer can be given that way. The AEC upper air program as yet does not have results which can clearly prove or disprove the hypothesis I have presented. It will have this information in the very near future.

Senator PASTORE. We have Dr. Brewer's thesis or theory that there is an element or a phenomenon that even though this injection was in the tropical part of the earth, it has directed itself toward the polar regions.

Dr. MACHTA. Correct, sir.

Senator PASTORE. Now, in order to develop that theory, you have to know what is up there?

Dr. MACHTA. Correct, sir.

Senator PASTORE. Otherwise, the theory means nothing?

Dr. MACHTA. Yes.

Senator PASTORE. Therefore, you do know it is there?

Dr. MACHTA. From other information that is classified. It is not the information I was just describing to Mr. Holifield. That will be unclassified.

Senator PASTORE. We know it is there.

Dr. MACHTA. Reasonably well. I will not say positively, but information available to me and to others—incidentally not myself alone—would suggest that is where it is located.

Senator PASTORE. If we did not know it was there, Dr. Brewer's theory would not amount to anything?

Dr. MACHTA. That might be so, sir.

Senator PASTORE. Well, it is so, sir.

Dr. MACHTA. Well, there are other possibilities. For example, it conceivably could have——

Senator PASTORE. Otherwise you would have a hypothesis upon a hypothesis that leads to nothing.

(Conference between Senator Pastore and Representative Holifield.)

Senator PASTORE. Well, all right.

Representative HOLIFIELD. We understand, sir, that you are under certain prohibitions in making testimony in public session, and I am sure this matter can be resolved in executive session.

Dr. MACHTA. Surely.

Representative PRICE. Mr. Chairman?

Representative HOLIFIELD. Mr. Price.

Representative PRICE. In reading a recent speech delivered by one of the Atomic Energy Commissioners on variations of strontium 90, he said:

> For air-fired megaton weapons our present indication is that the fallout is almost worldwide; and for reasons of simplicity, and in the absence of better information at the present time, we work on the model that this is a uniform distribution over the entire world of the material that falls from the stratosphere.

The way I read your statement, you do not quite agree with that.

Dr. MACHTA. In my view, sir, the information which is just now available, and which has been presented here, and which probably has been developed subsequent to the statement you have made, suggests otherwise.

Representative PRICE. This is a very recent speech. This speech was delivered in the latter part of April of this year.

Dr. MACHTA. The data were given to me only about last week or so, sir. This is the data in which the particular model I formulate has been put together, sir.

Representative PRICE. This was delivered before the spring meeting of the American Physical Society by Dr. Libby. It is at variance with the statement you made here this morning.

Dr. MACHTA. I believe the entire Sunshine program—"Sunshine" referring to the stratospheric or lifelong hazard from radioactive debris—is one which is in continual development, and this is not the only area in which modifications of the model and theories have been worked out as new data are obtained.

Representative HOLIFIELD. Are there further questions?

If not, we will excuse you, and thank you very much, Dr. Machta, for a very challenging presentation.

Your article on World Wide Travel of Atomic Energy Debris will be inserted at this point.

[Reprinted from Science, September 14, 1956, vol. 124]

WORLD-WIDE TRAVEL OF ATOMIC DEBRIS

L. Machta, R. J. List, L. F. F. Hubert[1]

For centuries meteorologists have thought of exploring large-scale atmospheric circulations by means of tracers. The literature describes how man has successfully tracked fluorescent particles to a distance of 100 miles,[2] used radioactive tracers across the United States,[3] and followed volcanic ash and forest fire smoke over distances of the order of 1000 miles.[4] Only the dust from a major volcanic eruption, such as Krakatao, has been tracked on a truly global scale.

During two of the nuclear test periods in the Pacific Proving Grounds of the U. S. Atomic Energy Commission, sufficient radioactive debris was thrown into the atmosphere to be deposited in both hemispheres. Measurements of the deposited radioactivity were obtained from exposed sheets of gummed film. The details of the network and the sampling and measurement techniques have been described by Eisenbud and Harley.[5] It should be noted, however, that the deposition of particles on the adhesive surface depends either on the presence of precipitation or, in dry weather, on turbulence to assist the impaction of the particles on the horizontal surface of the paper. It is thus possible to have a cloud of radioactive particles pass two stations simultaneously and have only the station with rain note the presence of the particles overhead. The gummed-film method of collection is recognized as being as crude as it is simple.

The nuclear explosions are treated in this article, the Mike shot on 1 November 1952 and the Bravo shot on 1 March 1954. The shots were similar in that both are described as having had energy in the megaton range, both were detonated at or near the earth's surface on a coral island, and both had atomic clouds that penetrated into the stratosphere. To the meteorologist, the main difference of interest between the two events is the season.

WINDS

The winds acting on the two atomic clouds at the time of detonation are illustrated in Fig. 1. The wind structure has been estimated, when necessary, from observations at nearby locations and times. On both days the tropopause was found at an altitude of about 55,000 feet, and it separated winds blowing from different directions. The easterly winds above the tropopause increased in speed to the highest altitude of the available wind information for the Bravo shot, while for Mike the easterly winds decreased in speed and ultimately changed to westerly winds. The easterly winds in the trade-wind layer, the moist maritime air mass lying near the sea, extended up to about 20,000 feet during the detonation of the Mike device, while for the Bravo shot they were below 10,000 feet. Between the trade-wind layer and the tropopause, one normally finds westerly winds. During the Mike shot these westerlies were temporarily interrupted and became southerly winds, while for the Bravo shot they were toward a more normal bearing.

In Fig. 2 is found the approximate area covered during the early days by that part of the nuclear cloud from the Mike shot which was located below the tropopause. The shaded areas in Fig. 2 have been deduced from meteorological considerations alone, and, in many cases, are subject to considerable uncertainty. Shading was discontinued when the meteorological data no longer warranted any reasonable estimate of the path. The light winds and sparsity of upper-wind observations have made tracing the upper tropospheric portion of the Mike cloud

[1] The authors are on the staff on the U. S. Weather Bureau, Washington, D. C.
[2] R. R. Braham, B. K. Seely, W. D. Crozier, Trans. Am. Geophys. Union 33, 825 (1952).
[3] R. J. List, Bull. Am. Meteorol. Soc. 35, 315 (1954).
[4] H. Wexler, Weatherwise 3, 129 (1950).
[5] M. Eisenbud and J. H. Harley, Science 124, 251 (1956).

particularly uncertain. For this reason, the time of passage across the North American mainland is unknown. Tracing was discontinued on 7 November. The tradewind portion of the nuclear cloud appears to have split south of Japan, the upper portion (near 20,000 feet) curving around a Pacific high cell and entering the United States about 9 November.

The estimated meteorological path of the Bravo cloud is shown in Fig. 3. The upper tropospheric portion of the nuclear cloud was traced to the Central American area by about 5 March, and an offshoot extending northward into the United States at about 20,000 feet was detected approximately 1 week later.

Differences between the paths of the Mike and Bravo clouds are evident from Figs. 2 and 3. In part, the differences are seasonal and in part due to the specific meteorology for the shot days. Thus, in November the mid-tropospheric westerly winds are not as strong as they are in March, and they are located farther north, on the average. Further, in November one finds an anticyclonic circulation not far from the Marshall Islands which is not typically present in March. The shallowness of the trade-wind layer during the Bravo shot is an example of a feature unusual for the region during any season.

There has been no attempt to track the stratospheric portions of the atomic cloud because of the sparsity of wind observations at these altitudes. Evidence from numerous isolated high-level winds, not necessarily obtained during the periods of the two nuclear tests, suggests a path that would travel around the earth at about the same latitude as the point of origin. It is interesting to note that in no case was it imperative to rely on stratospheric transport of the nuclear debris to account for the earliest arrival at any point, for the transport of the nuclear cloud in the troposphere appeared to account for the first observations of radioactivity.

An attempt to determine the earliest arrival time at the ground at each point of observation has been undertaken. The results, which are shown in Figs. 2 and 3 as the number of days after the shot day, should in many cases be viewed with caution. First, in many of the stations in the Southern Hemisphere, the deposited activity was so low that it made the arrival date almost meaningless. Second, despite elaborate precautions, it is likely that some gummed films were contaminated during handling. Finally, as noted in the second paragraph the apparent arrival time of the cloud at many stations coincided with rainfall, suggesting that the nuclear cloud may have been overhead some time earlier but that precipitation was required to bring its activity to earth.

FALLOUT

It is noted that, in accordance with the meteorological estimates, the fallout over the United States progressed roughly from west to east during the Mike shot. Fallout from the Bravo event did not appear at the West Coast stations in the United States until 2 weeks after one of the cloud protuberances entered the central United States. Of perhaps greatest interest, although also of greatest doubt, are the comparatively early arrival times in the Southern Hemisphere. Thus, for example, a literal interpretation of the chart reveals that every station in the Southern Hemisphere showed an earlier arrival time than did the United States West Coast stations for the Bravo case. Also of interest are the comparatively late arrival times for the mid-Pacific stations west of the Hawaiian Islands during the Mike fallout. These stations were south of one branch of the nuclear cloud and north of the other.

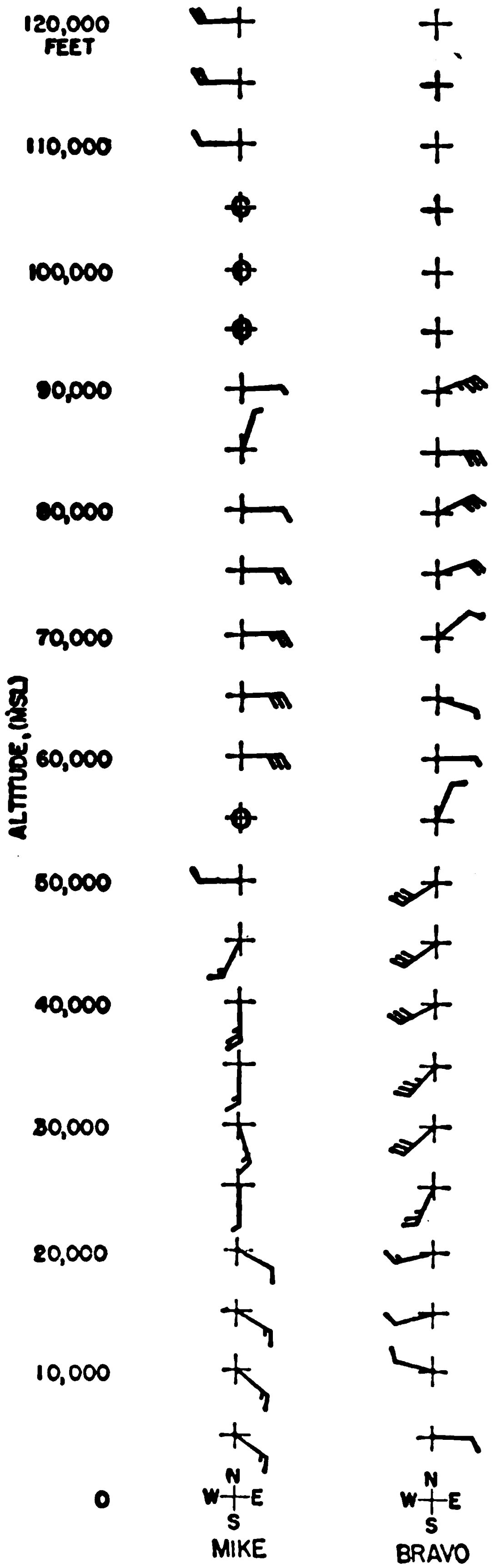


Figure 1.—Upper winds at shot time. Arrows blow with the winds, and barbs indicate wind speed; full barb, 10 knots; one-half barb, 5 knots.

The actual fallout at each station and an analysis of the data are shown on Figs. 4 and 5. The units are cumulative decayed beta activity for the first 35 days following each event and are approximately equivalent to millicuries per 100 square miles (the values have not been corrected for the efficiency of the gummed film.) Several features that differentiate the two maps should be noted. First, an average value for all United States and Canadian stations was obtained for the Mike shot, as opposed to values for individual stations during the Bravo shot. Second, the isolines located between points on the West Coast of the United States and points in the Western Pacific Ocean are also based on fallout observations obtained from transport vessels for Bravo. Finally, as is evident, the network was expanded between the two events, primarily in an attempt to locate stations in rainy areas. In many cases, when the period of record is incomplete or the data are suspect, parentheses have been placed around the number. No attempt has been made to reconstruct the isolines for the fallout that occurred within the first 24 hours of the shot.

The comparatively small values obtained at the Southern Hemisphere stations especially during the Mike shot, are immediately evident from the fallout maps. The northern part of the Northern Hemisphere, however, received equally small depositions. The distribution of fallout for the Pacific stations appears to be consistent with the features of the meteorology described, although the branching of the cloud south of Japan in the Mike pattern is based only on scanty observational evidence.

It is apparent that radioactive debris produced by nuclear explosions does not possess all the desired attributes of a tracer for studying global circulations. Information concerning the magnitude and distribution of the radioactivity that remains airborne after the initial fallout is not available. The debris, being particulate, is washed out of the atmosphere and cannot be strictly treated as a conservative property. Thus, for example, the depositions in the Southern Hemisphere may have been low because most of the debris was rained out as it passed southward through the Intertropical Convergence Zone. In addition, the most effective sampling program for the debris provides only the crudest measure of the fallout. Yet, despite these limitations, it appears that the meteorologist can obtain useful information by operating such a network of gummed films during nuclear test periods. Although it is not proposed that special nuclear tests be undertaken for meteorological purposes, it seems reasonable to expect even greater value from future tests using an expanded network and having detonations at other locations and times.

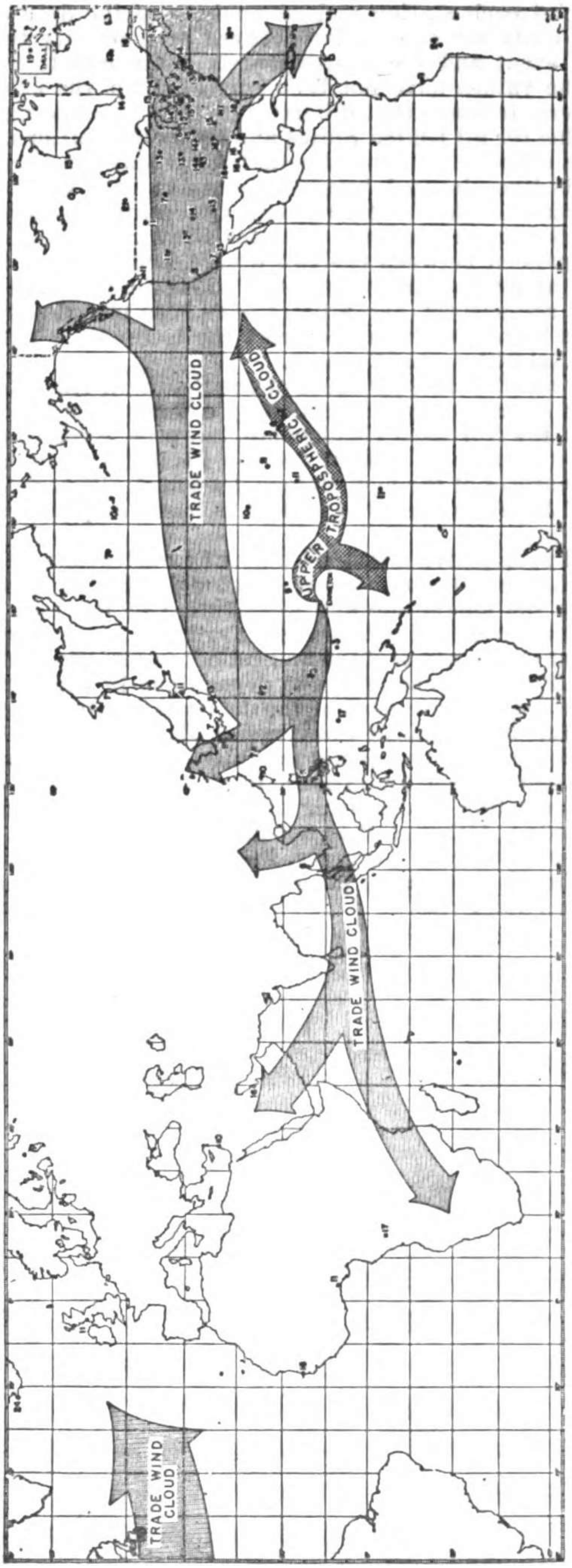


FIGURE 2.—Early history of the Mike cloud. The figures indicate the number of days between detonation and the first ground observation of fission products.

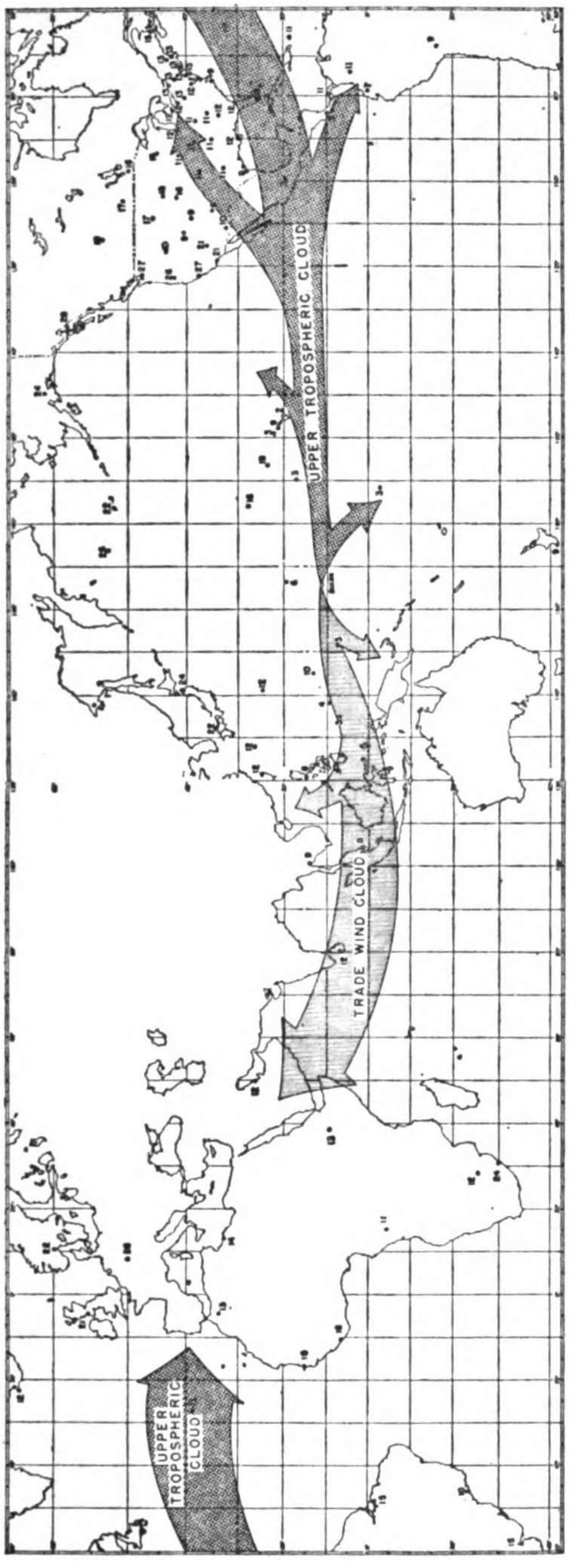


FIGURE 3.—**Early history of the Bravo cloud. The figures indicate the number of days between detonation and the first ground observation of fission products.**

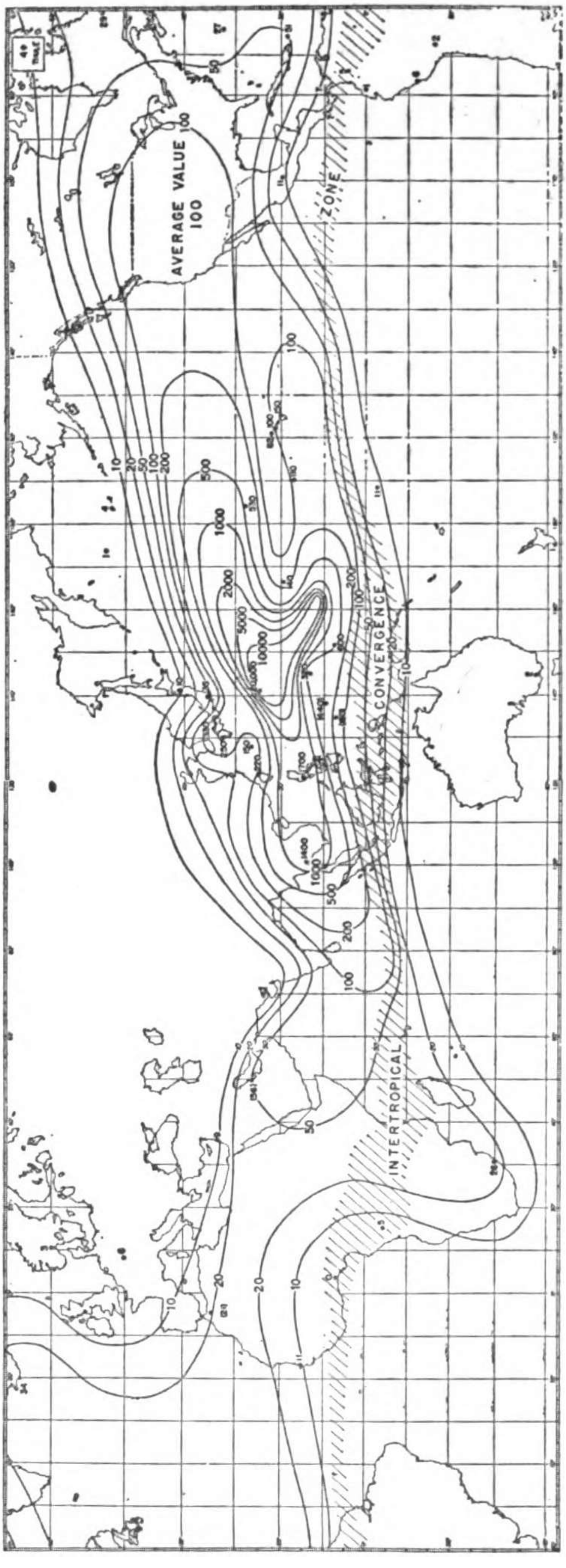


FIGURE 4.—Total radioactive fallout from the Mike cloud in the period from 2 to 35 days after detonation, in millicuries per 100 square miles. Hatching indicates the approximate November position of the Intertropical Convergence Zone, the belt of low pressure that tends to separate Northern and Southern Hemisphere air near the surface of the earth.

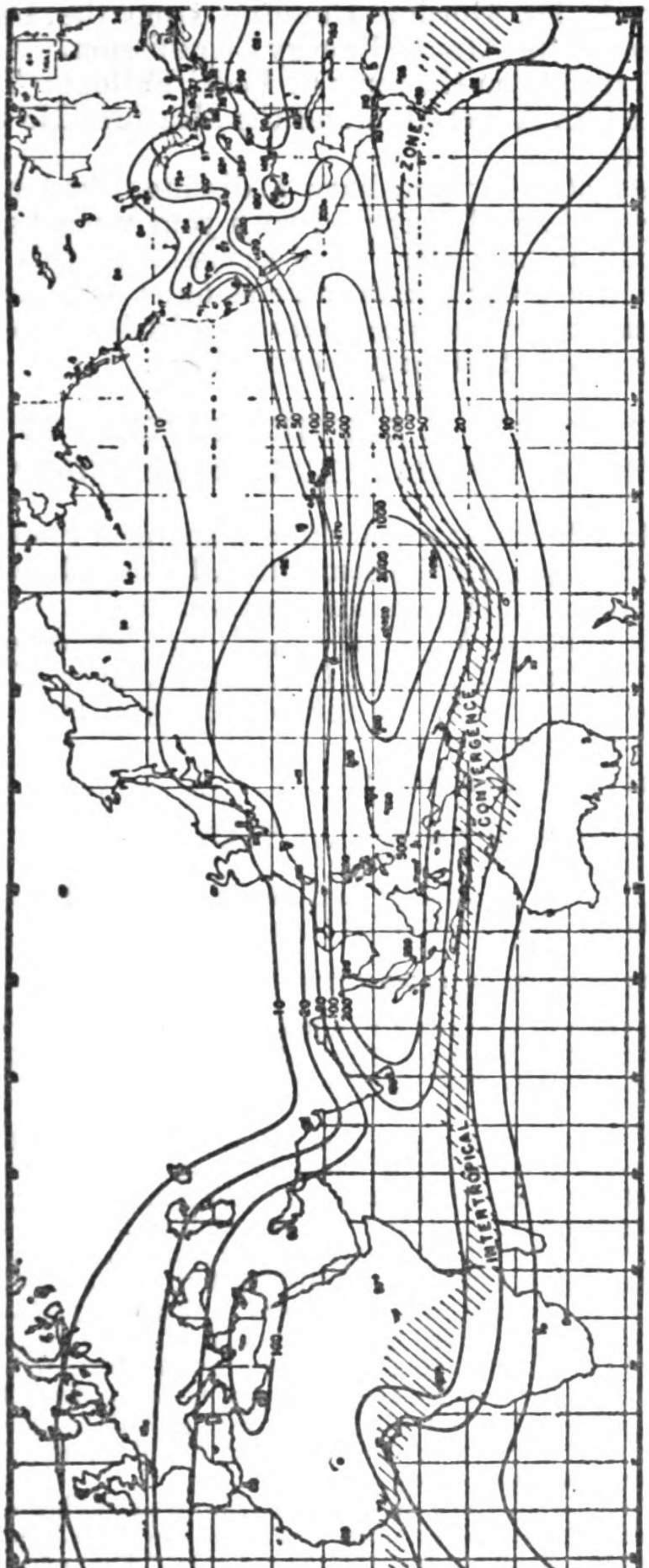


FIGURE 5.—Total radioactive fallout from the Bravo cloud in the period from 2 to 35 days after detonation, in millicuries per 100 square miles. Hatching indicates approximate March position of the Intertropical Convergence Zone, the belt of low pressure that tends to separate Northern and Southern Hemisphere air near the surface of the earth.

Our next witness is Dr. Gordon Dunning from the Division of Biology and Medicine of the Atomic Energy Commission.

Dr. Dunning will testify on the topic of Local Fallout: The Mechanisms by Which It Can Affect Man and the Measures He Can Take to Minimize Exposure.

Dr. Dunning, we note that you have a distinguished biography, and your biography will also be inserted with your remarks.

The committee will be in order. The acoustics in this room are very bad, and we will ask our guests to be as quiet as possible so all can hear. We will ask the witness to speak up a little bit louder than usual in his testimony so that all the people can hear.

STATEMENT OF DR. GORDON M. DUNNING, DIVISION OF BIOLOGY AND MEDICINE, ATOMIC ENERGY COMMISSION [3]

Dr. DUNNING. Mr. Chairman, since there is so much relevant material on this subject, if it pleases the committee, I would like to submit the rather voluminous written report for the committee.

Representative HOLIFIELD. Without objection, this report and a letter from David T. Shaw, Assistant General Manager of the AEC will be received for printing in the record, and you may give such summary as you feel necessary.

(The documents referred to follow:)

RADIATIONS FROM FALLOUT AND THEIR EFFECTS

Gordon M. Dunning, Division of Biology and Medicine, United States Atomic Energy Commission, Washington, D. C.

FORMATION OF RADIOACTIVE PARTICLES

At the time of detonation of a nuclear weapon, about 60 different isotopes are formed, representing some 35 elements. Most of these give rise to decay chains consisting of several isotopes so that there may be 170 isotopes produced eventually.

In terms of activity, a 1-megaton detonation (1 million tons) TNT equivalent energy produced by fission of atoms will result in about 300,000 megacuries of radioactivity, measured 1 hour after the burst. In addition there may be present induced radioactive isotopes resulting from the reaction of neutrons released at the time of detonation, with natural materials such as soil and water. (A fusion reaction produces no radioactive substances directly but may cause induced activity because of its release of neutrons.) The total radioactivity of the products of a fission reaction will greatly exceed that of the activity induced in the soil or water. In the case where the fireball clears the ground, there will be a relatively small percentage of the total fission product activity deposited around ground zero and the neutron-induced activity probably will be much greater. However, none of the neutron-induced isotopes that might be produced in appreciable quantities have long half-lives.

Shortly after a nuclear burst, some of the radioisotopes combine with oxygen to form negative radicals while the halogens form halides which combine with the strongly electropositive elements to form compounds. The noble gases such as radiokrypton and radioxeon remain in the atomic state until they decay to a

[3] Date and place of birth: September 11, 1910; Cortland, N. Y. Education: State Teachers College, Cortland, N. Y., 1929-33; New York University (6 weeks), 1933; State Teachers College, Cortland, N. Y., 1934-36; M. S. (Sci. Edu.), Syracuse University, 1941; doctor of education, 1948. Work history: Teacher, Middletown, N. Y., 1937-41; U. S. Army (Lt. Col.), 1942-46; instructor, New York Agricultural and Technical Institute, Alfred, N. Y., 1947-48; teacher, Phy. & Phy. Sci., Indiana, Penn., 1948-51; AEC, Biophysics Res. Anal. Div. B&M, 1951-53; AEC, Biophysicist, Division of Biology and Medicine, 1953-55; AEC, Radiation Effects Specialist, Division of Biology and Medicine, 1955—. (Submitted by the Atomic Energy Commission.)

daughter isotope which can form an oxide or halide. With the rapid cooling of the fireball, there is condensation of the isotopes and inert materials.

In the case of an air burst there will be available only small quantities of relatively fine particles of dust in the air and debris from the bomb casing to act as a transport vehicle for the radioisotopes. When the fireball intersects the ground the intense heat melts or vaporizes large quantities of soil and transports them aloft to act as carriers for the condensing radioisotopes. A characteristic toroidal motion sweeps this debris in and around the fireball where the melting temperature is reached and the particles come in contact with the fission products still in gaseous form. Subsequent cooling results in the radioactive isotopes becoming associated within and on the surface of the particles. It has been estimated that from 50 to 90 percent of these particles are between 50 and 1,000 microns in diameter. Of these, probably less than half of the larger particles falling out near the site of the detonation will possess any activity, since most particles will not reach sufficiently high temperatures to incorporate the radioactive materials, and dry, relatively cool, soil is a poor scavenger.

The high yield weapon detonated at the Pacific proving ground in the fall of 1952 resulted in a crater in the coral nearly a mile in diameter and 175 feet deep. Although a minor factor in the crater production might have been the compression of the coral by the blast, probably more than a hundred million tons of material were dislodged and thrown into the air. The exact results might not be reproduced for a detonation over continental land areas or built-up cities but in general the effects would be similar.

DISTRIBUTION OF RADIOACTIVE PARTICLES

For nominal bombs (in the range of 20-kiloton yield) the atomic cloud will not rise above the tropopause. (The tropopause marks the level below which is the turbulent airflow of the troposphere and above which is the relatively stable nonturbulent air of the stratosphere). The cloud from a high yield weapon will penetrate into the stratosphere as illustrated by the photograph on page 196 of the detonation during Operation Ivy in the fall of 1952. Two minutes after the explosion the cloud had risen to 40,000 feet and 10 minutes later neared its maximum height of over 100,000 feet. The smaller particles carried into the stratosphere will settle only very slowly until they reach the troposphere where the turbulent air and rainfall will carry them much more rapidly to the earth's surface.

The stratospheric storage is uniquely significant since the mixture of radioisotopes present there is enriched in strontium 90, the element of most concern for long-term hazards. This is because strontium 90 has a gaseous precursor krypton 90 with a half life of 25 seconds. Thus, at the time when conditions are optimum in the fireball for the oxides and halides to become associated with molten inert particles, only a fraction of strontium 90 has formed and the gaseous krypton parent is largely carried into the stratosphere. This results in the nearby fallout (within several hundred miles downwind) being partially depleted in strontium 90 while at more distant areas will be enriched.

The activity placed in the stratosphere circles and recircles the earth, first at the same general latitude as the burst and then slowly spreading laterally. At the same time there will be a slow diffusion into the tropopause. Initially, there will be more deposition in the same hemisphere (northern or southern) in which the burst occurred but after many months the rate of deposition may become more generally uniform over the entire earth's surface. In terms of strontium 90 about 10 to 20 percent of the activity remaining in the stratosphere may descend each year.

The distribution of the nearby fallout (up to several hundred miles downwind) from high yield weapons detonated near the earth's surface will be determined principally by particle size, initial position in the stem and cloud, and by the wind structure at various altitudes. The particle sizes and the distribution of these particles within the stem and cloud are principally functions of the yield of the bomb, the nature of the surface over which the burst occurs and the quantity of material vaporized. There are uncertainties in our knowledge but figure 1 presents one generalized concept of such an initial distribution. Although the cloud may be 100 miles in diameter the activity probably is not uniformly distributed, but rather is more concentrated near the central and lower portions of the cloud.

The influence of the wind structure at various altitudes on the ground distribution of the nearby fallout is qualitatively represented in figure 2. The last sketch

in figure 2 illustrates the effects of the "shearing" action of the winds when they travel in different directions and/or speeds at the various altitudes through which the particles must fall. Due to these wind conditions, it is possible to obtain fallout patterns ranging from one looking like an ink blot around ground zero at one extreme, to other situations where the fallout material is spread in a long thin finger. In general, the pattern may be expected to approximate an ellipse.

It is clear that such variables as wind conditions and the yields of nuclear bombs and their positions of detonation above different types of surface make it possible to predict fallout patterns precisely. In the case of nuclear weapons testing these variables are either known or can be predicted with good accuracy. However, in civil defense planning, certain assumptions concerning these variables must be used in estimating not only a single fallout pattern, but also possible overlapping patterns in the event of multiple detonations.

RADIATIONS AND FALLOUT

In describing and evaluating the effects of fallout patterns, it is necessary to consider the characteristics of the radiations emitted from the radioactive material. These are of three types: Gamma rays, beta particles, and alpha particles. Gamma rays are the emissions of principal concern, because of their greater penetrating power. The most energetic beta particles travel only a few yards in air and are of concern only when the fallout materials remain in contact with or in very close proximity to the skin, or when tne emitting materials find their way into the body. The amount of alpha-emitting isotopes associated with fallout material is considered to be of relatively minor consequence.

EXTERNAL GAMMA EXPOSURE

The gamma radiation dose that one may actually receive and the biological effects are dependent upon a number of factors, as follows:

1. *Radiological decay*

The decrease in radioactivity of fallout material roughly follows the relationship of $(\text{time})^{-1.2}$. This means that, for every sevenfold lapse of time after a nuclear explosion, there will be a tenfold reduction in dose rate. For example, if fallout occurs 1 hour after a detonation, such as might occur for 20 or 30 miles around ground zero of a high-yield weapon, the dose rate will be one-tenth of its initial value by the seventh hour. An additional tenfold reduction would require 7 times 7 hours or approximately 2 additional days of waiting. The theoretical[1] dose accumulated from the first to seventh hour after detonation would be approximately the same as that from the seventh hour until 1 week later. Further, this first-week dose would be about twice as great as the entire remaining dose possible for the lifetime of the activity (fig. 3). This rapid decay suggests the benefits of protection in the early periods after fallout and, where possible, delay of entry into a contaminated area.

In localities downwind where initial fallouts might not occur until, say, 24 hours after a detonation, the situation would be somewhat different, in that the radioactive decay would be slower. For example, consider the cases where fallout occurred at (*a*) 1 hour, and (*b*) 24 hours, after a detonation. One day after fallout the dose rate in the first case would be one-forty-fifth of its initial activity (1st hour), but in the second case the dose rate would have decreased to only slightly less than one-half of its initial activity (24th hour).

The above estimates are based on an assumed radiological decay of $(\text{time})^{-1.2}$. This is reasonably accurate for early periods of time after detonation, but the decay may start to vary significantly from the theoretical curve after several months have elapsed (fig. 4). At times later than shown in figure 4 the decay curve would be expected to flatten out due to the presence of long-lived cesium 137 (27-year half life).

2. *Weathering and shielding effects*

The magnitude and time of occurrence of weathering and shielding makes it impossible to establish a single establishment of a precise rule of effects covering all situations, impossible, yet, these factors are operative in determining the total exposure received from fallout.

[1] Calculations of theoretical doses are based on (*a*) the radioactivity decreasing according to $(\text{time})^{-1.2}$, (*b*) there is no loss of activity by weathering effects, and (*c*) the person is out of doors for the time considered.

One example of weathering effects was after the March 1, 1954, fallout on the Marshall Islands in the Pacific. Figure 4 shows the gamma dose rates on the island of Rongelap over a period of about 2 years. In the first 10 days when the winds were light and there was no rainfall, the decrease in activity was roughly consistent with known radiological decay rate. The break between the 10th and 25th day undoubtedly represents the effects of rain which was known to have occurred in that period. Figure 4 suggests, however, that any further reduction in contamination by rainfall was slight.

An example of the effects of winds, occurred after one of the nuclear detonations at the Nevada test site in 1953. Strong winds blew almost at right angles across a narrow band fallout field on the 2d and 3d day after the detonation. The gamma dose rates at 3 feet above the ground on the 4th day were less than predicted by the relationship of $(\text{time})^{-1.2}$ by factors ranging from 3 to 6, while the activity of the soil samples collected on the first day and taken into the laboratory did decrease approximately as $(\text{time})^{-1.2}$. This effect of winds would not be expected to be as great for large contaminated areas of nonsandy soils.

Calculations of shielding and attenuation factors for different types of materials and theoretical calculations for various structures are plentiful (references through 11) (table 1), but more information based on actual field experience is needed. Limited data were obtained during Operation Teapot (spring 1955) where film badges were placed inside and outside of buildings for several days. The ratio of out-of-doors to indoors doses ranged from 1.3 to 7 with 1-room frame buildings providing the least attenuation factor and multiroom concrete block buildings the greater values. This program will be expanded during Operation Plumbbob as will the program of estimating personnel exposure by having a large number of people living around the Nevada test site wear film badges during and following the test series.

3. Gamma energy spectra

The relative biological effectiveness of differing energy photons and their varying depth-dose curves has been shown for X-rays (12). Similar results have been obtained for gamma rays as illustrated by one set of experiments (13) using burros where there was a shift of LD 50/30 values (lethal dose to 50 percent of the exposed animals who died in 30 days) from 684 roentgens with cobalt 60 (1.25 Mev mean energy) to 585 roentgens with Zr-95—NB-95 (~0.7 Mev mean energy). The gamma energy spectra from the mixture of isotopes in fallout is quite complex and is further complicated by the presence of scattered radiation, with its lesser energies, mixed with the direct radiation. Figure 5 illustrates the estimated gamma spectra at 3 feet above the ground following the detonation of March 1, 1954, at the Pacific Proving Ground (14).

4. Geometry of the source

The geometry of the source can make a significant difference in depth-dose curves and resultant biological effects. This may be illustrated by one experiment using swine where the LD 50/30 values for external dose decreased from 500 to 350-400 roentgens when the exposure was changed from unilateral to bilateral (the radiation exposure was first on one side only, then from opposite sides of the subject) (12). With a fallout field, the source probably would be more radial, thus a roentgen as measured in air would have more biological effect than one where the source is unilateral such as from the immediate radiations at the instant of a burst (although there is some scattered radiation), or from X-ray machines which have been used frequently with unilateral beams in developing data on biological effects of radiation.

5. Biological repair factor

It has been recognized that, in general, the longer the period over which a given radiation dose is delivered, the less is the resultant biological effect, except for such aspects as the genetic effects and life shortening. In situations of heavy fallout and relatively large potential radiation doses, the biological repair factor may be considered in estimating incapacitating and lethal doses. Since past experiments usually have been designed for other purposes, the data from these do not readily elucidate the rate of repair or the proportions of reparable and irreparable damage resulting from differently timed doses. Varying relationships have been demonstrated, depending upon the species or even the strain of animal, as well as the criteria selected for study, such as skin damage, life shortening, and LD 50 values. Our present knowledge does not permit establishment of a precise overall relationship for timed doses versus biological effects;

yet there are sufficient convincing data to permit an attempt at estimating the effect of this phenomenon.

Blair, Smith, Sacher, Davidson (15, 16, 17, 18, 19) and others have made extensive analyses of existing data on the effects of time-spaced doses for several species of animals. Generally, the recovery rate for larger and longer lived mammals, such as dogs, is significantly less than for mice. One estimate places the half-time recovery for man as long as 4 weeks (the time for one-half of the biological damage to be repaired) (19).

Since the estimated rate of biological recovery for man is relatively slow, this factor would have its greatest influence where a given total radiation dose was delivered over long periods of time. This would be the case where the fallout occurred at later times after detonation rather than close-in areas where the fallout is essentially complete in about an hour after the burst, and about one-half of the total possible dose is delivered in the first 24 hours.

NEARBY FALLOUT FROM HIGH YIELD WEAPONS

As an exercise during the National Association of Civil Defense Directors meeting in Washington, D. C., on April 15–17, 1957, it was assumed the 4 bombs were dropped simultaneously as follows: 20 megaton on the Union Station Washington, D. C., 5 megaton on the National Airport, 20 megaton on Baltimore, Md., and 10 megaton on the Patuxent River Naval Air Station. The map on page 195 shows that combined fallout from these 4 bombs. The isodose rate lines are in units of roentgens per hour at 1 hour after detonation. By this time essentially all of the fallout would have occurred in these nearby areas.

Recalling that the radioactive decay is rapid for this fallout that occurs early after detonation, it becomes evident that if adequate protective areas are available it would be wiser for people to remain in place, rather than be exposed out of doors during the period of highest activity. Likewise, if a delay in movement is possible there will be more of an opportunity to evaluate the situation, and to then affect an orderly evacuation.

Since each situation will be unique, no rigid criteria will be proposed here for permissible exposures or for mandatory evacuation, since there may be other factors present as potentially hazardous as radiation. Rather, table 2 was developed to illustrate the kind of thinking and planning possible for civil defense. Three levels of exposure to civil defense workers are shown. The lowest of 25 roentgens is much higher than is permitted in peactime, yet most personnel will retain their full working capacity even with exposures up to 100 roentgens.

Table 2 suggests several points relative to rescue. One of these, is that higher permitted radiation exposures to rescue crews would allow earlier entry into the contaminated area to affect first aid and general rescue work. Also, in the case of relatively little protection to the populace, there would be a saving in radiation exposure to them. On the other hand, people better sheltered, as illustrated in column V, would receive less total expoure if they stayed in the protected areas until the out-of-doors activity had decreased, and at the same time a delay of entry into the contaminated area would result in less radiation exposure to the rescue crews who might then be used again for other missions.

DISTANT FALLOUT PATTERNS FROM HIGH YIELD WEAPONS

The discussion above suggests the wide variability possible in distant fallout patterns from high-yield weapons and the great variation in radiation dose that one may receive due to shielding and weathering effects. Therefore, the following analysis is intended to be only a generalized one to illustrate the parameters and how they may operate in determining the radiation doses.

Consider the case of fallout from a high-yield weapon where people continue to live in an area without any special measures to protect themselves. Assume (*a*) for the first week following the fallout, the measured gamma activity decays according to $(\text{time})^{-1.2}$, for the second week $(\text{time})^{-1.3}$, and for the third week and thereafter $(\text{time})^{-1.4}$, and (*b*) the shielding factor afforded by normal housing will reduce the out-of-doors daily dose by 25 percent, and (*c*) the half-time of repair of biological injury is 4 weeks. Probably all of these assumptions are conservative, i. e., they overestimate the hazard. Based on these assumptions, figure 6 shows the dose rates at time of fallout or entry into an area that might produce an "effective biological dose" (the term given to the radiation exposure according to the above assumptions) of one roentgen (20). This

graph may be extrapolated to other readings. For example, if a fallout begins 5 hours after detonation and the dose rate at that time is 10 r. per hour, about 67 r. (effective biological dose) will be accumulated provided personnel continues to live normally in the contaminated area. This is computed as follows:

$$\frac{10}{0.15}=67$$

It is frankly recognized that in any single curve, such as that shown in figure 6, there are inherent a number of uncertainties. Criteria based on deliberate analyses of the relevant data, however, may be more valid than those determined under the duress of an emergency situation. Such a simplified graph might provide radiological monitors with a quick, even if rough, estimate of the potential hazards and thus assist in making decisions on questions such as evacuation.

Using figure 6, the idealized fallout diagram on page — was constructed to illustrate a possible pattern from a single high-yield surface burst (20).

The two innermost isodose lines shown were selected to suggest regions where (*a*) a significant percentage of personnel might be expected to die (400 r.) and (*b*) a few percent to become ill (100 r.), assuming continued occupancy of these areas with no special protective measures. These percentages would, of course, rise within the encompassed areas. The 50 r. effective biological isodose line has no unique significance, but suggests the magnitude of dose which might call for emergency measures against radiation exposures even in the face of other possible hazards. Table 3 shows the approximate areas encompassed by the three isodose lines. For areas where the fallout occurs a few hours or more following detonation, many days or weeks will be required to accumulate the major portion of effective biological doses, so that spot decisions involving additional hazards might not be necessary.

The question is frequently asked as to the time one must spend within a shelter or remain outside of a contaminated area. The answer depends upon a number of parameters, such as the criteria established for maximum permissible dose, as well as length of stay within the area of contamination . With knowledge of the magniture of the radiation levels present and an assumed rate of decay, $(t)^{-1.2}$, it is possible to plan and execute a short stay, even in a highly contaminated area. Planning for continuous occupancy requires more extensive analysis. The following data may aid in such evaluation.

The fall out map (idealized fallout diagram on page 196) and table 3 suggest the degree of radiation exposure received in continuous occupancy under normal living conditions beginning with the time of initial fallout. For those entering the contaminated zone 4 months after the first fallout, however, and then living there indefinitely, the area encompassed by the 50 r. effective biological isodose line will have shrunk from about 25,000 to 2,500 square miles. At such time (4 months after fallout), an area of about 1,000 square miles within the 50 r. isodose line might have the highest residual contamination, amounting to about 3 times the does rates at the periphery. The 0.3 r. per week, out-of-doors, isodose-rate line might extend to about the same position as the line marked "50" on the map.

As one attempts to extrapolate such data to 1 year after fallout, the analysis becomes still more difficult and uncertain. The data suggest, however, that if return is postponed to 1 year after fallout, the 50 r. effective biological isodose line will have disappeared. On the basis of these conservative estimates, the 1,000 square miles of highest contamination might have an out-of-doors dose rate of about 4 r. per week after 1 year. Similarly, personnel might accumulate a dose of about 100 r. for the first year following their return, and an additional 90 r. over the next 3 years, independent of the biological recovery factor. It is to be expected that this factor would be relatively great for such long periods of time, thus reducing the effective biological dose below 50 r. The 0.3 r. per week, out-of-doors, isodoserate line might encompass an area somewhat larger than the line marked 400 on the map (20).

For such effects as genetic, it is the total dose received that is important, since biological repair does not enter in such calculations. According to the conservative estimates of weathering and shielding used above, possibly several hundred roentgens might be delivered in the areas of heaviest contamination, from the end of the first year after the fallout occurred until the radioactivity had decreased to essentially zero. However, the foregoing analyses are based on passive factors only, not taking into account the actions of persons themselves in reduc-

ing contamination. If, for example, a permanent return into an area were postponed for 1 year after fallout, the radiological situation probably would have been adequately appraised, and decontamination operations initiated. (This subject will be discussed by others.) Moreover, with the return of a populace into a known contaminated area, more than normal precautions might be expected in regard to occupancy of the more protective types of buildings and reduction of time spent out of doors.

Of course, greater degrees of contamination could result from multiple, overlapping, fallout patterns. There is a need for continuing studies of these problems.

ENVIRONMENTAL CONTAMINATION

Radioactive contamination of an area will, of course, influence agricultural pursuits. An evaluation of these problems involves complex and difficult studies which will not be attempted here. In terms of civil defense, however, there is one phase that should be noted here.

The relatively heavy fallout that occurred on some of the Marshall Islands in March 1954 provides the most direct data. Since the time of this fallout there have been 10 radiological and biological surveys of these islands. All of these data are summarized in a report prepared by the Atomic Energy Commission and in press with the Government Printing Office (21).

There are strikingly wide variances in the degree of gross contamination in the soils and in the plant and animal life. Likewise, relatively large ranges in values were found for the individual isotopes in the plants and animals. Any conclusions, therefore, must be of only the most tentative and generalized nature.

The data do suggest that, in terms of strontium 90, the isotope of principal concern, this activity built up in the plantlife over the first year after fallout and then started decreasing slowly. By using very rough approximation, and extrapolations, the data suggest that, if plantlife had been growing in the area of great contamination, i. e., where the gamma dose rates extrapolated to H plus 1 hour would have been 2,500 roentgens per hour, it might have contained 10–30 microcuries of strontium 90 per kilogram of calcium, at 1 year. The corresponding values for the soils are several times higher. If an assumption is made that there is a discriminatory factor of about 4 for the Sr-Ca ratio in plants versus bones, the above data suggest possible levels of strontium 90 in the bones of animals from continuous consumption of this food of a few to several microcuries of strontium 90 per kilogram of calcium. The maximum permissible body burden for adult atomic-energy workers is 1 microcurie of strontium 90 per kilogram of calcium.

There is some confirmatory evidence for this crude evaluation. A variety of native animals were left on the island of Rongelap after the fallout in March 1954. They have been collected and sacrificed serially in time. Even after 2 years of continuous occupancy, it was reported that there were no pathological changes that could be ascribed to radiation (22). Their bones showed from about a one-tenth to a few tenths of a microcurie of strontium 90 per kilogram of calcium. Since the areas of highest contamination were about 12–14 times greater than Rongelap, an extrapolation would suggest values in the same range as above, i. e., a few to several microcuries of strontium 90 per kilogram of calcium if animals had lived in the area of great contamination.

The Pacific island soils have higher calcium content than most soils in the United States, and of course there are differences in the type of plantlife and in the climate. However, theoretical calculations suggest that the same fallout in the United States might result in something like 100 microcuries of strontium 90 per kilogram of calcium in the soils with the highest contamination. With assumed discriminatory factors from soil to bones of 10 or more, the implied eventual body burden of strontium 90 is of the same magnitude in the Pacific.

The uncertainty of these data, however, would not deny the possibility that for a similar fallout in the United States there might eventually result a body burden of 10 or more microcuries per kilogram, if people were to subsist entirely on food from the area of highest contamination. With maintained values 2 to 3 times this amount, it might be expected that a few percent might die of bone tumors after a latent period of 15 to 20 years. It would be expected, however, that the strontium 90 content in the food supply would slowly decrease with time. Any measures taken to reduce the uptake of strontium 90 into the food supply, and any supplemental foods from less contaminated areas would lower the strontium intake.

For civil-defense purposes, a full evaluation of the whole environmental contamination problem is needed, especially for the cases of multiple, overlapping, fallout patterns from many nuclear detonations which might occur under wartime conditions.

EXTERNAL BETA EXPOSURE

The second principal emission from the fallout material is beta particles. These are essentially high-speed electrons, of which even the most energetic travel only a short distance into the skin. (See the next section for discussion on internal exposures.) If large enough radiation doses are delivered by these beta particles, the skin may first show erythema (reddening) and then proceed to more serious damage. If a sizable fraction of the body should suffer serious skin damage from these beta radiations, the results would be similar to those from thermal burns, i. e., serious injury or death.

There is little doubt that "beta burns" can and have occurred. In the case of the Marshallese who were in the fallout from the detonation at the Pacific on March 1, 1954, most of the more heavily exposed showed some degree of skin damage, as well as about half of them showing some degree of epilation due to beta doses (22). However, none of these effects were present except in those areas when the radiation material was in contact with the skin, i. e., the scalp, neck, bend of the elbow, between and topside of the toes. No skin damage was observed where there was a covering of even a single layer of cotton clothing. In fact, the beta radiations emanating from the radioactive material on the ground should have been adequate to produce detectable skin damage (based on the amount of contamination present), yet this was not observed.

These findings indicate the obvious benefits to be expected from (*a*) remaining inside during the time of actual fallout to reduce the possibility of direct body contamination, or, if out of doors, to keep the body covered, and (*b*) early removal of the body contamination, since higher doses are delivered during early times after fallout.

The Marshallese were semiclothed, had moist skin, and most of them were out-of-doors during the time of fallout. Some bathed during the two-day exposure period before evacuation, but others did not, therefore, there were optimal conditions in general for possible beta damage. The group suffering greatest exposure showed 20 percent (13 individuals) with deep lesions; 70 percent (45 individuals) superficial lesions; and 10 percent (6 individuals) no lesions. Likewise, 55 percent (35 individuals) showed some degree of epilation followed by a regrowth of the hair. However, during this same period of time they received a whole-body gamma dose of 175-roentgens—a value approaching lethality for some of those exposed. These data, together with others, indicate that the external gamma radiation would be the controlling factor for making such decisions as to evacuation, although recognizing that any beta exposure would be an additional body insult.

INTERNAL EXPOSURES

The principal factor in evaluating long-term hazards from ingestion and inhalation is the doses delivered to the bones by isotopes of strontium. This subject will be discussed in detail by others.

The principal hazards from intake of relatively large amounts of radioactive fallout for several weeks immediately following a nuclear detonation are doses to the:

(*a*) gastrointestional tract, from the gross fission product activity,
(*b*) thyroid, from isotopes of iodine, and
(*c*) bone, principally from isotopes of strontium and barium-lanthanum.

The solubility of the fallout material is a major factor in determining the resultant fate, and thus radiation doses, within the body. The solubility varies, depending among other factors upon the surface over which the detonation occurred. The fallout material collected in soil samples at the Nevada test site has been quite insoluble, i. e., only a few percent in distilled water and roughly 20 to 30 percent in 0.1 N HCI. However, it would be expected that the activity actually present in drinking water supplies would be principally in soluble form. The water collected from a well and a cistern on the island of Rongelap about 21 months after the March 1, 1954, fallout, was found to have about 80 percent of the activity in the filtrate, but there was an undetermined amount that settled to the bottom. Other data suggest the material to have been about 10 to 20 percent soluble in water.

Figure 7 shows relative doses to the body organs, based on the assumptions that (*a*) 90 percent of the material is insoluble (when calculating doses to the

gastrointestinal tract), (*b*) all of the isotopes of iodine are soluble (when estimating doses to the thyroid), and (*c*) 25 percent of the ingested strontium isotopes and 7 percent of the barium-lanthanum reached the bones. It may be seen that ingestion of a given amount of fission product activity on the fourth and fifth days may result in nearly 2½ times the dose to the thyroid as to the lower large intestine. For a continuous consumption of fallout material from the 1st hour to the 30th day the ratio of doses is about 1.7. Table 4 indicates the amount of ingested fission product activity to produce 1 rad dose to the lower large intestine.

Analyses of past data strongly indicate the quantity of fallout material taken in for times immediately following a detonation: (*a*) by inhalation is very much less than by ingestion (unless of course one does not eat or drink), and (*b*) may come from surface contamination of the food rather than by the soil-plant-animal cycle.

How much intake is actually permitted depends upon many factors including the essentialness of the food and water to sustain life, and one's philosophy of acceptable biological risks and damages in the face of other possible hazards such as mass evacuation. By using table 4 and figure 7, an estimate may be made of the radiation doses that might result from the ingestion of a given amount of fission product activity. In determining how much actual ingestion, and thus the radiation doses that might be permitted, reference may be made to table 5 which suggests the biological effects from certain doses.

Such evaluations as attempted here are necessary and valuable for planning purposes, but once the fallout occurs the emergency of the situation may preclude immediate analysis of the food and water suppiles. Further, the abstinence from food and water because it might be contaminated could not be continued indefinitely. Therefore, the following three commonsense rules are suggested:

1. Reduce the use of contaminated food and water to bare minimum until adequate monitoring can be performed; use first any stored clear water and canned or covered foods; wash and scrub any exposed foods.
2. If the effects of lack of food and water become acute, then use whatever is available but in as limited quantities as possible. Whenever possible select what seems to be the least likely contaminated water and/or foodstuffs.
3. Since it is especially dsirable to restrict the intake of radioactivity in children, give them first preference for food and water having the lowest degree of contamination.

In an area of heavy fallout one matter to consider is the relative hazards from the external gamma exposure versus internal doses from ingestion of the material. One of the best evidences on this point was the fallout that occurred on the Rongelapese in March 1954. Those in the highest exposure group received 175 roentgens whole body external gamma exposure yet their body burdens of internal emitters were relatively low (22). These and other data suggest that:

If the degree of contamination of an area for several weeks immediately following a nuclear detonation is such that the external gamma exposure would permit normal and continuous occupancy, the internal hazard would not deny it.

This is based on such reasonable assumptions of (*a*) about 50 percent reduction of gamma exposure from out-of-doors doses afforded by living a part of each day in normal family dwellings, (*b*) washing and/or scrubbing contaminated foods, and (*c*) excluding areas where relatively little fallout occurred, but into which may be transported highly contaminated food and/or water. After longer periods of time during which the gamma dose rates in an originally highly contaminated area have decreased to acceptable levels, it probably would be necessary to evaluate the residual contamination for the bone seeking radioisotopes, especially strontium 90.

NUCLEAR WEAPONS TESTING

Since 1951, the United States has conducted 11 series of nuclear tests, 5 at the Nevada test site and 6 at the Eniwetok Proving Ground, for a total of more than 63 test detonations. A sixth series is currently underway at the Nevada test site. The fallout on the inhabitants of some of the Marshall Islands in March 1954 (which will be discussed by others) and fallout on some Japanese fishermen, have been the major effects off the testing areas. The only other off-site damage has been in the United States where the blast wave has caused minor structural damage for which about $45,000 has been paid in claims (23), and fallout that occurred on some horses and cattle grazing within 20 miles of ground zero causing skin burns for which about $15,000 was paid.

At the Eniwetok Proving Ground, where the larger devices are tested, the warning area covers nearly 400,000 square miles. This area is under constant sur-

veillance during the time of testing both by surface ships and by aircraft. Starting 2 days prior to a detonation, the search is intensified in the sector of probable fallout. If any transient ship is located in the warning area, it is advised to leave and the detonation is delayed until it is clear.

Fully manned weather and fallout prediction units are an integral part of the task force conducting the tests. Since the larger detonations in the Pacific require additional information on the upper air, new types of high-altitude balloons and missiles are used. Nine weather stations are established by the task force during the test series on islands around the site, in addition to the eight regular weather stations in operation on other islands.

After each detonation, aircraft track the radioactive air out for several hundred miles. Other aircraft, with special monitoring equipment fly over land and sea areas to measure any residual contamination.

Through the cooperation of the United States Public Health Service; trained monitors were present during Operation Redwing (spring 1956 series) on the populated islands of Wotho, Ujelang, and Utirik.

As would be expected, the delineation of fallout patterns in the wide expanses of the Pacific is difficult. For the immediate monitoring, aerial surveys are conducted as mentioned above, automatic equipment are placed on land areas, and a variety of ships, skiffs, and buoys are utilized. Following each test series, large-scale radiological and biological surveys are made. Data from these surveys have been summarized by the Commission in a document soon to be published by the Government Printing Office (21).

The Nevada test site covers an area of about 600 square miles, with the adjacent 4,000 square miles being a United States Air Force gunnery range (24). Surrounding these areas are wide expanses of sparsely populated land. For general safety, as well as security, the Nevada test site is closed to the public. Aerial and surface surveys are made to insure that no persons or animals wander into the area. Each nuclear detonation is publicly announced ahead of time.

As a part of the test organization there is an advisory panel of experts in the fields of biology and medicine, blast, fallout prediction, and meteorology. A series of meetings is held before the firing of each shot to weigh carefully all factors related to the safety of the public.

A complete weather unit is in operation at the Nevada test site, drawing upon all of the extensive data available from the United States Weather Bureau and the Air Weather Service, plus six additional weather stations ringing the test site. These data are evaluated for the current and predicted trends up to 1 hour before shot time. A shot can be canceled at any time up to a few seconds before the scheduled detonation. In the past, more than 80 postponements have been made due to unfavorable weather conditions.

Several measures have been used to reduce the radioactive fallout off the test site. First, of course, only small nuclear devices are tested at Nevada. Since the greater the height of the fireball above the surface the less is the fallout in nearby areas, the test towers have been extended to 500 feet, and during Operation Plumbbob (spring 1957) there will be at least one 700-foot tower. Also, a new technique of using captive balloons is being developed. Extensive tests are being conducted to determine the feasibility of detonating nuclear devices so far underground that all of the radioactive material will remain captured and thus, of course, completely eliminate any fallout.

Prior to each nuclear detonation a warning circle is established for aircraft, designed to provide control of aerial flights within the area of predicted path of the atomic cloud. A representative of the Civil Aeronautics Administration is assigned to the test organization and assists in establishing the controlled area. This may typically extend about 150 miles in radius and be in force for a period from about H minus one-half hour to H plus 10 hours. All aircraft are required to check through the Civil Aeronautics Administration before flying in this area.

After each nuclear burst, aircraft from the test organization track the cloud until it is no longer readily detectable. Behind this come other aircraft to plot the fallout pattern on the ground. This survey is repeated on D plus 1 day.

The off-site monitoring program during Operation Plumbbob (spring 1957) illustrates the extensive system organized not only to take numerous radiological measurements but also to provide close liaison with the citizens of nearby communities. The Atomic Energy Commission and the United States Public Health Service jointly organized a program wherein the areas around the test site are mapped out into 17 zones. A technically qualified man has been assigned to live in each zone. His duties consist not only of normal monitoring activities

but also, prior to and during the test series, of learning the communities and families in his zone, getting to know the people and having them know him. In addition to the 17 zone commanders, as they are called, there are 8 mobile monitoring teams on call to go to any locality to assist if needed or to travel to areas outside the 17 zones.

Four additional monitoring programs are also in operation. One of these projects is primarily of research nature yet provides radiation monitoring data out to 160 miles or more from the test site. A second program is a unique system of telemetering, whereby instruments are placed in about 30 communities around the test site and connected to commercial telephone wires. The operator sits at the control point and, by placing a normal telephone call, receives back signals that are translated in a matter of seconds into gamma radiation dose rates. A third project consists of automatic instruments located in another 15 communities that permanently record the gamma dose rates continuously from the beginning to the end of the test series. A fourth program consists of aerial surveys with special gamma detection instruments.

Extending outward from the test site across the country are 38 United States Public Health Service monitoring stations established in cooperation with the Atomic Energy Commission, and 11 AEC installations (see tables 6 and 7). In addition, through the cooperation of the United States Weather Bureau 93 stations in the United States make gummed paper collections of fallout (table 7). These gummed-paper collections are also made worldwide at 73 other locations by arrangement with the Department of State, United States Weather Bureau, United States Air Force, and Navy (table 9).

RADIATION EXPOSURES TO THE PUBLIC

The data and their evaluation concerning strontium 90 produced by nuclear weapons testing will be discussed by others at this hearing.

The external gamma exposures through September 1955 may be described briefly as follows:

"* * * With respect to the gamma dose, the average value for the United States is higher than it is for the rest of the world. The range of values in the United States is relatively narrow, 6 to 49 millirads, except for Salt Lake City (160), Grand Junction (120), and Albuquerque, N. Mex. (110). The representative dose for eastern United States is about 15 to 20 millirads, with slightly higher values in the Middle West and lower values on the west coast.

"The cumulative gamma dose at the foreign stations is in the range of 4 to 23 millirads, except for some of the Pacific islands, where the range is from 13 to 150 millirads * * *" (25).

These are infinity does, i. e., the maximum possible exposures one might receive if he were out of doors for the lifetime of the radioactivity, there were no weathering effects, and the activity decayed according to $(\text{time})^{-1.2}$. The actual radiation exposures will vary with changes in these conditions, but roughly may approximate one-half of the infinity dose.

In summarizing, the data on radiation exposures from fallout, the National Academy of Sciences-National Research Council report said (26):

"* * * it may be stated that United States residents have, on the average, been receiving from fallout over the past 5 years a dose which, if weapons testing were continued at the same rate, is estimated to produce a total 30-year dose of about *one-tenth of a roentgen;* and since the accuracy involved is probably not better than a factor of 5, one could better say that the 30-year dose from weapons testing if maintained at the past level would probably be larger than 0.02 roentgens and smaller than 0.50 roentgens. * * *

"The rate of fallout over the past years has not been uniform. If weapons testing were, in the future, continued at the largest rate which has so far occurred (in 1953 and 1955) then the 30 year fallout dose would be about twice that stated above. * * *"

Gamma radiation exposures near the Nevada test site are generally higher that the average for the United States. The map on page 195 shows the estimated gamma exposures accumulated from all tests at the Nevada test site. Table 10 lists all of the communities that have received sufficient fallout to result in an estimated 0.2 roentgens or more to the inhabitants. In addition to this list, the highest fallout level noted to date in an inhabited place around the Nevada test site occurred in 1953 at a motor court near Bunkerville, Nev., where about 15 people might have accumulated 7 to 8 roentgens if they had continued to live there indefinitely.

The National Academy of Sciences-National Research Council Report recommended: (26)

"* * * That for the present it be accepted as a uniform national standard that X-ray installations (medical and nonmedical), power installations, disposal of radioactive wastes, experimental installations, testing of weapons, and all other humanly controllable sources of radiations be so restricted that members of our general population shall not receive from such sources an average of more than 10 roentgens, in addition to background, of ionizing radiation as a total accumulated dose to the reproductive cells from conception to age 30. * * *

"* * * That individual persons not receive more than a total accumulated dose to the reproductive cells of 50 roentgens up to age 30 years * * * and not more than 50 roentgens additional up to age 40 * * *."

The National Committee on Radiation Protection and Measurement (27) has recommended that, "The maximum permissible dose to the gonads for the population of the United States as a whole from all sources of radiation, including medical and other manmade sources, and background, shall not exceed 14 million rems per million of population over the period from conception up to age 30, and one-third that amount in each decade thereafter. Averaging should be done for the population group in which cross-breeding may be expected." (27)

Since natural background radiation is roughly 4 roentgens per 30 years, the value for manmade sources becomes about 10 million man-rems for a population of one million. This particular unit was selected because of genetic considerations, that is, radiation doses to relatively large populations. The average exposure to only those communities around the Nevada test site that experienced the greatest amount of fallout (0.2 roentgens or more) is 0.6 roentgens for the 6 years since the regular nuclear tests were started. The round numbers are 58,000 man-roentgens for 100,000 people. If the area considered around the Nevada test site is enlarged to include 1,000,000 people the average exposure is about 0.1 roentgens for the 6 years, or at a rate of about one-half roentgen per 30 years. This is one-twentieth of the recommendation of the National Committee on Radiation Protection and Measurement for maximum exposures.

The highest measured concentration of fission product activity in the air off the Nevada test site was at St. George, Utah, during the spring 1953 test series, amounting to about 1.3 microcuries per cubic meter of air averaged over a 24-hour period. It was estimated that the radiation dose to the lungs from this activity was less than that delivered every month by naturally occurring radioactive isotopes in the air that we breathe.

The highest measured concentration of activity from fallout material in water off the controlled area was at upper Pahranagat Lake, Nev., in the spring of 1955 amounting to 1.4×10^{-4} microcuries per milliliter at 3 days after the detonation. This is one-thirty-sixth of the operational guide—an amount that is considered safe for continuous consumption.

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Table 1.—Rough estimate of reduction in gamma radiation within structures

Type structure	*Percentage of out-of-doors level*
One-story frame house:	
First floor	~50
Basement (center)	~10
Basement (side)	<10
Multistory reinforced concrete:	
Lower floors (away from windows)	<10
Basement	~0.1
Shelter (equivalent to 3 feet of earth)	~0.1

TABLE 2.—*Radiation exposure*

Permissible dose to rescue crew (roentgens)[1]	Time of initial contact with populace (hours after detonation)	Dose to populace while waiting rescue (roentgens)[2]	Total radiation dose to populace (roentgens)[3]	Dose to populace while waiting rescue (roentgens)[4]	Total radiation dose to populace (roentgens)[3]
1	2	3	4	5	6
100 r/hr line:					
25	5½	72	85	14	26
50	2½	40	65	8	33
100	1¼	10	60	2	52
300 r/hr line:					
25	16	320	332	64	76
50	8½	260	285	52	77
100	5	205	260	41	91
500 r/hr line:					
25	25	600	612	120	112
50	14	500	525	100	125
100	7¼	400	450	80	130

[1] Based on a 2½-hour mission to rescue crew.
[2] Assuming ½ of out-of-doors exposure.
[3] Assuming populace receives ½ of exposure to rescue crew.
[4] Assuming 1/10 of out-of-doors exposure.

TABLE 3.—*Approximate areas encompassed by the effective biological isodose lines shown in the map (top of p. 196)*

Isodose line (r):	*Approximate areas encompassed (square miles)*
50	25,000
100	12,500
400	5,000

TABLE 4.—*Approximate fission product activities (microcuries per milliliter of gram × 10²) to produce 1 Rad dose to lower large intestine* [1]

Duration of ingestion (days)	Start of intake (days after detonation)							
	1 (1st hour)	2 (24th hour)	3	4	5	10	15	20
1	35	2.5	1.9	1.7	1.4	1.1	1.1	1.0
2	24	1.7	1.1	0.89	0.81	0.62	0.57	0.53
3	15	1.3	0.82	0.65	0.56	0.41	0.40	0.37
4	13	1.0	0.65	0.53	0.46	0.33	0.30	0.29
5	12	0.9	0.57	0.44	0.39	0.28	0.25	0.22
10	9.2	0.64	0.40	0.29	0.25	0.17	0.14	0.13
15	7.8	0.53	0.33	0.26	0.21	0.13	0.11	0.097
20	7.5	0.49	0.29	0.21	0.18	0.11	0.089	0.079

[1] (a) Activities computed at start of intake period. (b) Based on intake of 2,200 milliliters or grams of water and food per day for adults.

TABLE FIVE

SOME POSSIBLE BIOLOGICAL EFFECTS FROM RADIATION DOSES TO SPECIFIC ORGANS *

Dose (Rads)	Gastrointestinal Tract	Thyroid	Bones
10,000		Minor changes in structure	
	Permanent or serious damage — survival threatened		Tumor production
1,000	Tumor Production		
	Immediate effects such as nausea and vomiting		Minor changes in structure
		Potential carcinogenic dose to thyroids of few percent of children and adolescents	
100			

*Lesser short term effects would be expected from the same doses distributed in time.

TABLE 6.—*U. S. Public Health Service monitoring stations during operation Plumbbob (spring 1957)*

Albany, N. Y.
Anchorage, Alaska
Atlanta, Ga.
Austin, Tex.
Baltimore, Md.
Berkeley, Calif.
Boise, Idaho
Cheyenne, Wyo.
Cincinnati, Ohio
Denver, Colo.
El Paso, Tex.
Gastonia, N. C.
Harrisburg, Pa.
Hartford, Conn.
Honolulu, T. H.
Indianapolis, Ind.
Iowa City, Iowa
Jacksonville, Fla.
Jefferson City, Mo.
Juneau, Alaska
Klamath Falls, Oreg
Lansing, Mich.
Lawrence, Mass.
Little Rock, Ark.
Los Angeles, Calif.
Minneapolis, Minn.
New Orleans, La.
Oklahoma City, Okla.
Phoenix, Ariz.
Pierre, S. Dak.
Portland, Oreg.
Richmond, Va.
Salt Lake City, Utah
Santa Fe, N. Mex.
Seattle, Wash.
Springfield, Ill.
Trenton, N. J.
Washington, D. C.

TABLE 7.—*AEC monitoring stations during operation Plumbbob (spring 1957)*

Berkeley, Calif: Radiation laboratory, University of California
Cincinnati, Ohio: General Electric Co., aircraft nuclear propulsion department
Idaho Falls, Idaho: Idaho Operations Office
Lemont, Ill.: Argonne National Laboratory
Los Alamos, N. Mex.: Los Alamos Scientific Laboratory
New York, N. Y.: New York Operations Office
Richland, Wash.: Hanford Operations Office
Oak Ridge, Tenn.: Oak Ridge National Laboratory
Rochester, N. Y.: The atomic energy project, University of Rochester
Salt Lake City, Utah: Radiobiology laboratory, University of Utah
West Los Angeles, Calif.: Atomic energy project, University of California, Los Angeles

TABLE 8.—*U. S. Weather Bureau fallout sampling stations in operation during Operation Plumbob (spring 1957)*

Abilene, Tex.
Albany, N. Y.
Albuquerque, N. Mex.
Alpena, Mich.
Amarillo, Tex.
Atlanta, Ga.
Bakersfield, Calif.
Baltimore, Md.
Billings, Mont.
Binghampton, N. Y.
Bishop, Calif.
Boise, Idaho
Boston, Mass.
Buffalo, N. Y.
Caribou, Me.
Casper, Wyo.
Charleston, S. C.
Cheyenne, Wyo.
Chicago, Ill.
Cleveland, Ohio
Colorado Springs, Colo.
Concord, N. H.
Corpus Christi, Tex.
Concordia, Kan.
Dallas, Tex.
Del Rio, Tex.
Denver, Colo.
Des Moines, Iowa
Detroit, Mich.
Elko, Nev.
Ely, Nev.
Eureka, Calif.
Fargo, N. Dak.
Flagstaff, Ariz.
Fort Smith, Ark.
Fresno, Calif.
Goodland, Kans.
Grand Junction, Colo.
Grand Rapids, Mich.
Green Bay, Wis.
Hatteras, N. C.
Helena, Mont.
Huron, S. Dak.
Jackson, Miss.
Jacksonville, Fla.
Kalispell, Mont.
Knoxville, Tenn.
Las Vegas, Nev.
Los Angeles, Calif.
Louisville, Ky.
Lynchburg, Va.
Marquette, Mich.
Medford, Oreg.
Memphis, Tenn.
Miami, Fla.
Milford, Utah
Milwaukee, Wis.
Minneapolis, Minn.
Mobile, Ala.
Montgomery, Ala.
New Haven, Conn.
New Orleans, La.
New York (LaGuardia), N. Y.
Philadelphia, Pa.
Phoenix, Ariz.
Pittsburgh, Pa.
Pocatello, Idaho
Port Arthur, Tex.
Portland, Oreg.
Prescott, Ariz.
Providence, R. I.
Pueblo, Colo.
Rapid City, S. Dak.
Reno, Nev.
Rochester, N. Y.
Roswell, N. Mex.
Sacramento, Calif.
Salt Lake City, Utah
San Diego, Calif.
San Francisco, Calif.
Scottsbluff, Nebr.
Seattle, Wash.
Spokane, Wash.
St. Louis, Mo.
Syracuse, N. Y.
Tonopah, Nev.
Tucson, Ariz.
Washington, D. C. (Silver Hill, Md.)
Wichita, Kans.
Williston, N. Dak.
Winnemucca, Nev.
Yuma, Ariz.

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TABLE 9.—*Foreign monitoring stations during Operation Plumbbob (spring 1957)*

Addis Ababa, Ethiopia	Mexico City, Mexico
Anchorage, Alaska	Midway Island
Bangkok, Siam	Milan, Italy
Beirut, Lebanon	Misawa, Japan
Belem, Brazil	Moncton, New Brunswick, Canada
Bermuda	Monrovia, Liberia
Buenos Aires, Argentina	Montreal, Quebec, Canada
Canal Zone	Moosoonee, Ontario, Canada
Canton Island	Nagasaki, Japan
Churchill, Manitoba, Canada	Nairobi, Kenya, East Africa
Clarke AFB, Philippines	Nome, Alaska
Colombo, Ceylon	North Bay, Ontario, Canada
Dakar, French West Africa	Noumea, New Caledonia
Deep River, Ottawa, Ontario, Canada	Oslo, Norway
Dhahran, Saudi Arabia	Ponape
Durban Natal, South Africa	Prestwick, Scotland
Edmonton, Alberta, Canada	Pretoria, South Africa
Fairbanks, Alaska	Quito, Ecuador
French Frigate Shoals	Regina, Saskatchewan, Canada
Goose Bay, Labrador	Rhein Main, Germany
Guam	San Jose, Costa Rica
Hilo, Hawaii	San Juan, Puerto Rico
Hiroshima, Japan	São Paulo, Brazil
Honolulu, Hawaii	Seven Islands, Quebec, Canada
Iwo Jima	Sidi Slimane, French Morocco
Johnson Island	Singapore
Juneau, Alaska	Stephenville, Newfoundland
Keflavik, Iceland	Sydney, Australia
Koror	T'ai-pei, Formosa
Kwajalein	Thule, Greenland
La Paz, Bolivia	Tokyo Air Base, Japan
Lagens, Azores	Truk
Lagos, Nigeria	Wake Island
Leopoldville, Belgian Congo	Wellington, New Zealand
Lihue	Wheelus AFB, Tripoli
Lima, Peru	Winnipeg, Manitoba, Canada
Melbourne, Australia	Yap

Table 10.—Estimated radiation exposures for communities around the Nevada test site

NEVADA

	Roentgen		Roentgen
Acoma	3.0	Las Vegas	0.2
Alamo	1.3	Lincoln Mine	4.0
Ash Springs	0.6	Lockes Ranch	1.3
Baker	0.8	Logandale	0.4
Barclay	2.0	Lund	0.8
Buckhorn Ranch	0.9	Mesquite	1.8
Bunkerville	4.3	McGill	0.4
Caliente	0.7	Moapa	0.8
Carp	3.6	Nellis AF Base	0.05
Clarks Station	0.8	North Las Vegas	0.2
Crestline	0.7	Nyala	1.7
Crystal	4.0	Overton	0.35
Crystal Springs	1.0	Pahrump	0.2
Currant	0.5	Panaca	0.65
Dry Lake	1.0	Pioche	0.7
Duckwater	0.8	Preston	0.7
East Ely	0.6	Reed	4.0
Eden Creek Ranch	0.7	Rox	3.0
Elgin	3.5	Ruth	0.5
Ely	0.6	Sharp's (Adaven)	1.2
Eureka	0.2	Shoshone	0.7
Fallini Ranch	0.8	Sunnyside	1.2
Glendale	0.7	Ursine	0.6
Groom	2.0	Warm Springs	0.5
Hiko	1.0	Warm Spring Ranch	1.0
Kimberley	0.5		

UTAH

	Roentgen		Roentgen
Alton	0.8	Modena	0.5
Anderson Junction	1.2	Mount Carmel	0.85
Bear Valley Junction	0.4	New Castle	0.6
Beaver	0.25	New Harmony	1.2
Beryl	0.5	Orderville	1.5
Beryl Junction	1.0	Panguitch	0.2
Cedar City	0.4	Paragonah	0.4
Enterprise	0.7	Parowan	0.4
Garrison	0.7	Pintura	1.2
Glendale	1.2	Rockville	3.0
Gunlock	2.6	Saint George	3.0
Hamilton Fort	0.6	Santa Clara	3.5
Hurricane	4.2	Shivwits	2.8
Kanab	1.6	Springdale	2.6
Kanarraville	1.2	Toquerville	2.0
Leeds	3.0	Veyo	2.0
Long Valley	0.8	Virgin	1.5
Lune	0.5	Washington	3.0
Minersville	0.2	Zane	0.3

ARIZONA

	Roentgen		Roentgen
Beaver Dam	2.0	Short Creek	1.6
Littlefield	1.6	Wolf Hole	1.3

FIGURE 1

GENERALIZED CONCEPTS: DIMENSIONS OF CLOUD AND STEM DISTRIBUTION OF ACTIVITY

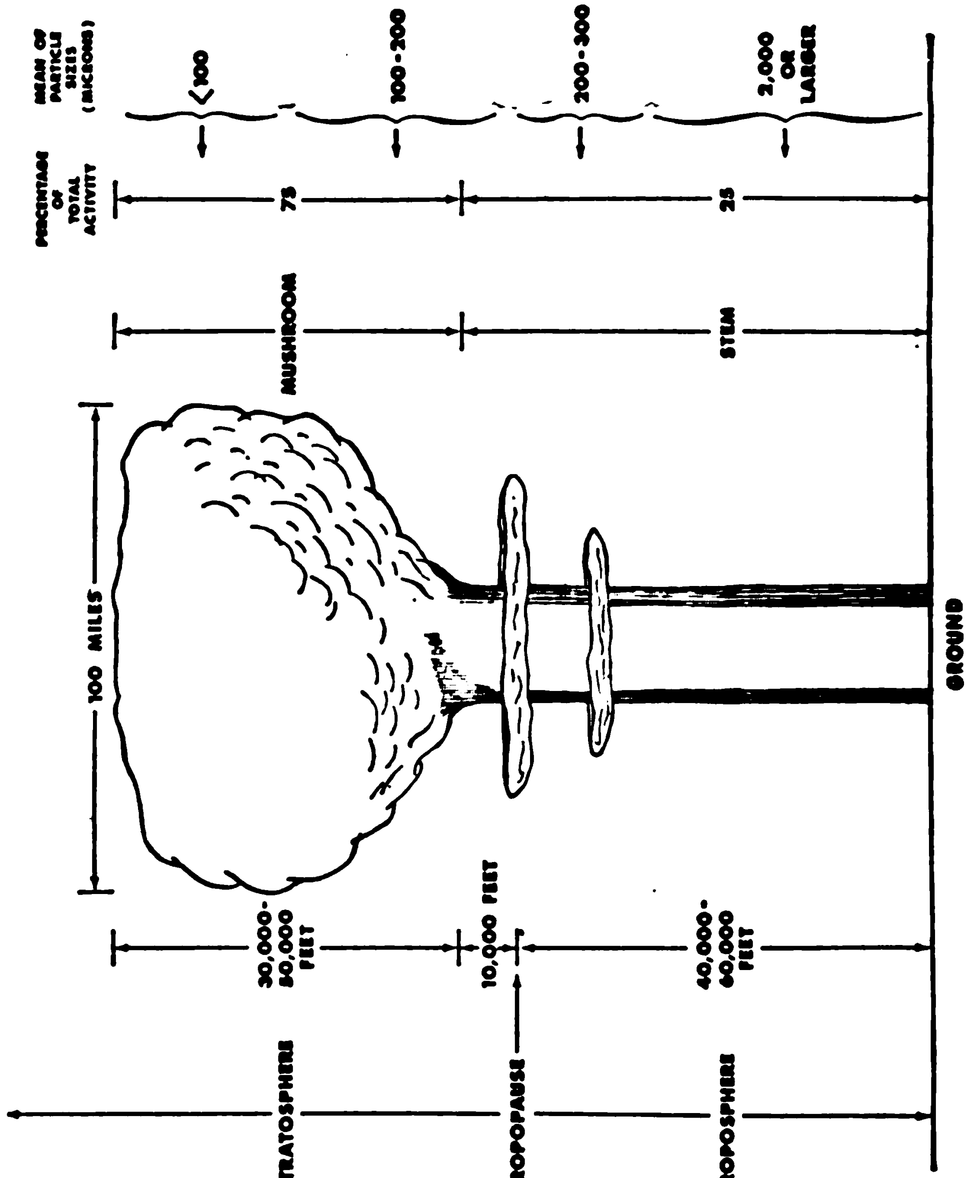
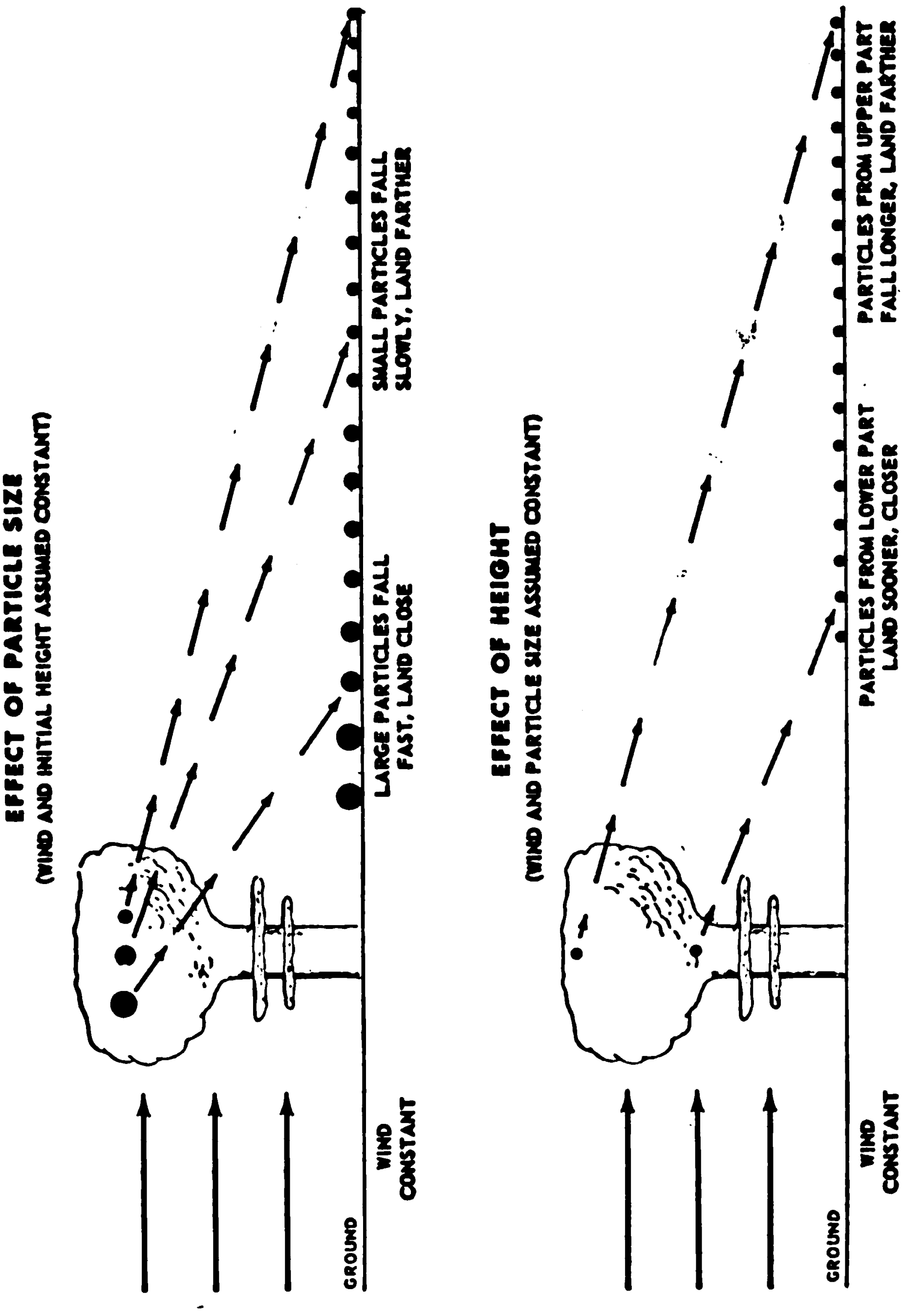


FIGURE 2a

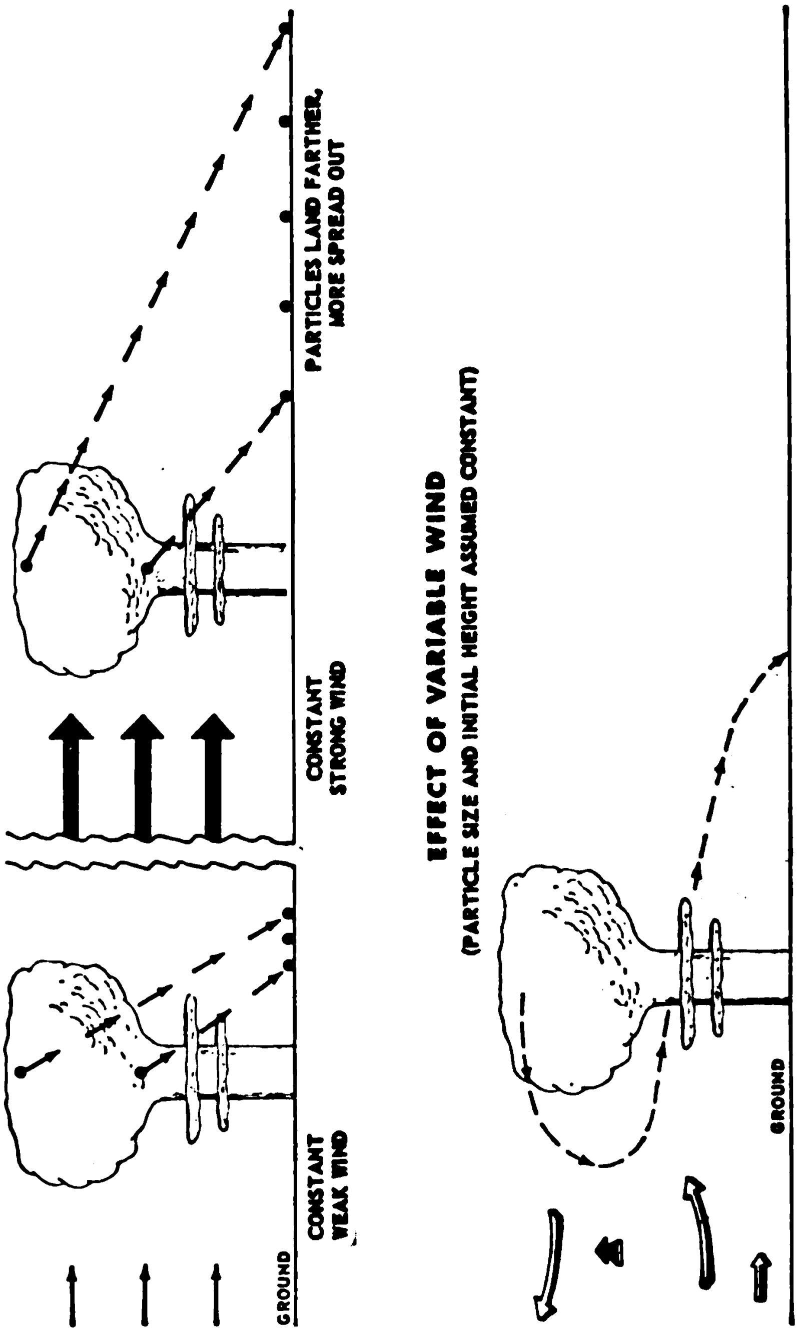
FACTORS AFFECTING DISTRIBUTION OF FALLOUT*



* As suggested in Civil Defense Technical Bulletin TB-11-21, Fallout and The Winds, October, 1955.

FIGURE 2b

FACTORS AFFECTING DISTRIBUTION OF FALLOUT *



* As suggested in Civil Defense Technical Bulletin TB-11-21, Fallout and The Winds, October 1955.

FIGURE 3

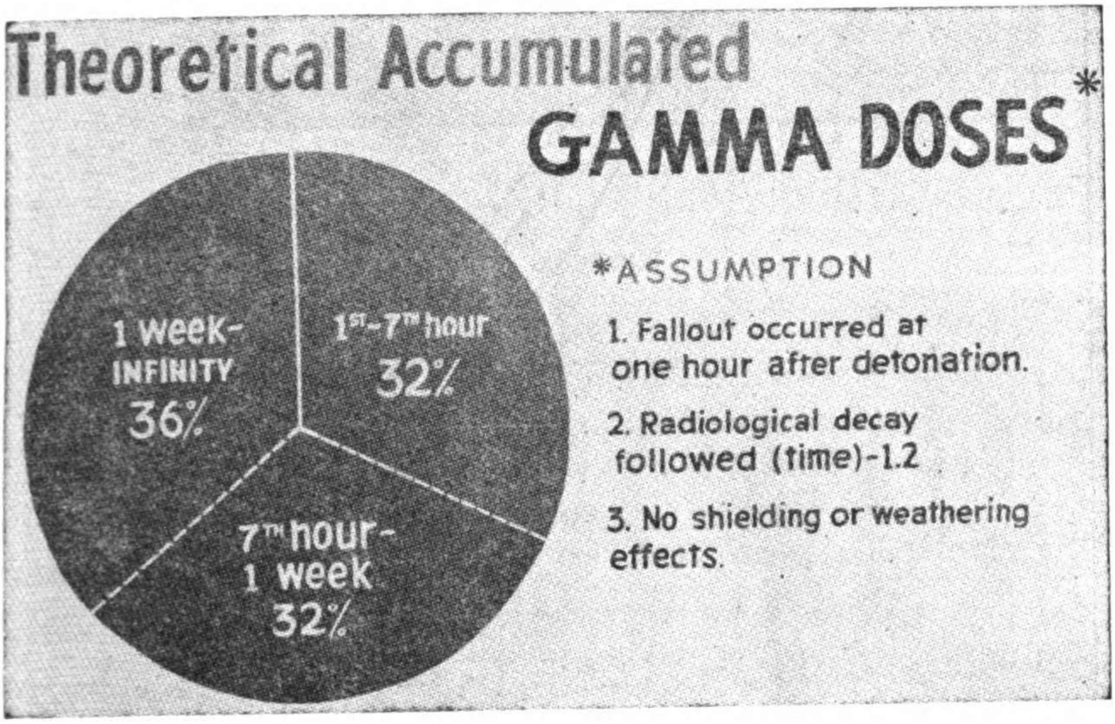

Theoretical Accumulated
GAMMA DOSES*
1 week-
INFINITY
36%
1st-7th hour
32%
7th hour-
1 week
32%
*ASSUMPTION
1. Fallout occurred at one hour after detonation.
2. Radiological decay followed (time)-1.2
3. No shielding or weathering effects.

FIGURE 4

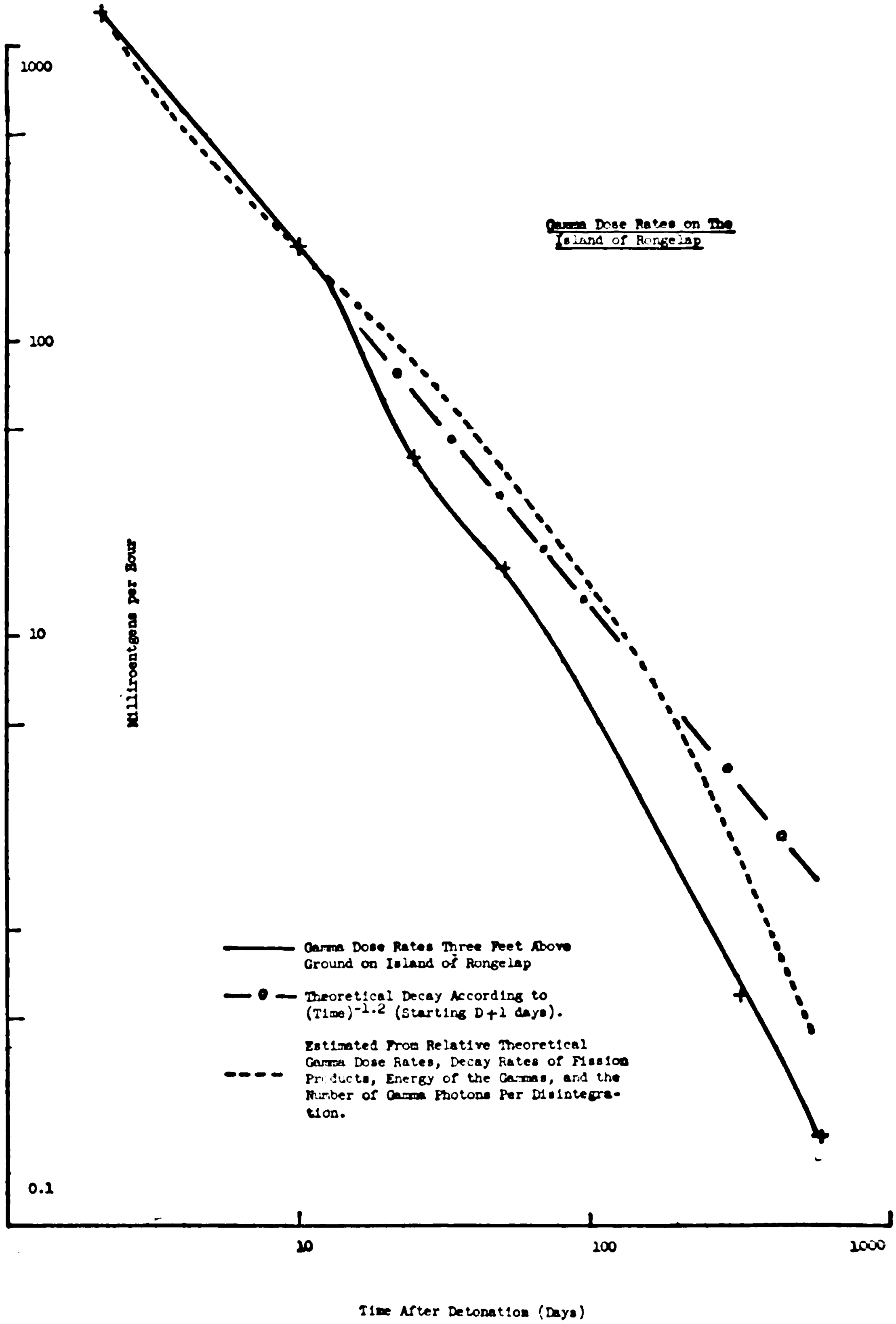

Gamma Dose Rates on The Island of Rongelap
1000
100
10
0.1
Milliroentgens per Hour
10
100
1000
Time After Detonation (Days)
Gamma Dose Rates Three Feet Above Ground on Island of Rongelap
Theoretical Decay According to (Time)$^{-1.2}$ (Starting D+1 days).
Estimated From Relative Theoretical Gamma Dose Rates, Decay Rates of Fission Products, Energy of the Gammas, and the Number of Gamma Photons Per Disintegration.

FIGURE 5

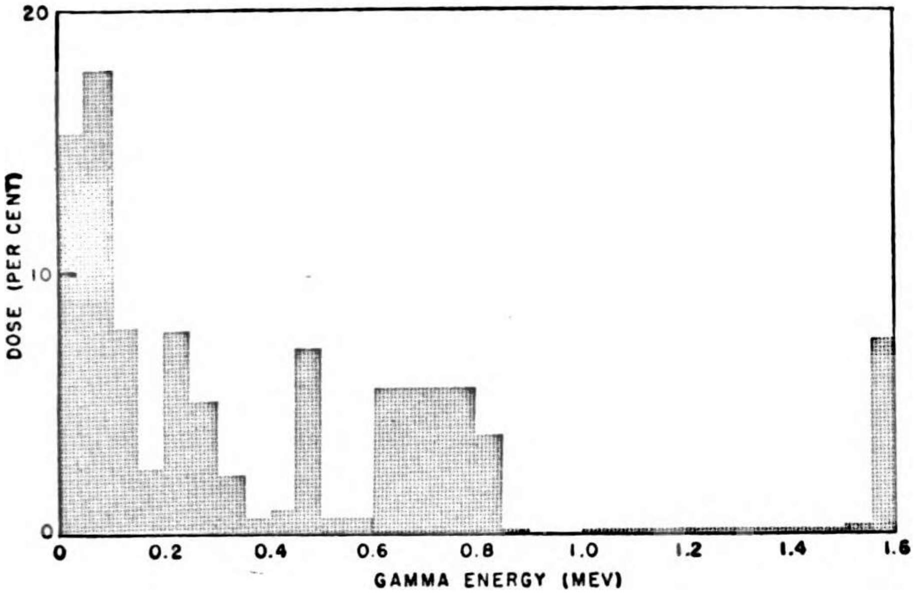
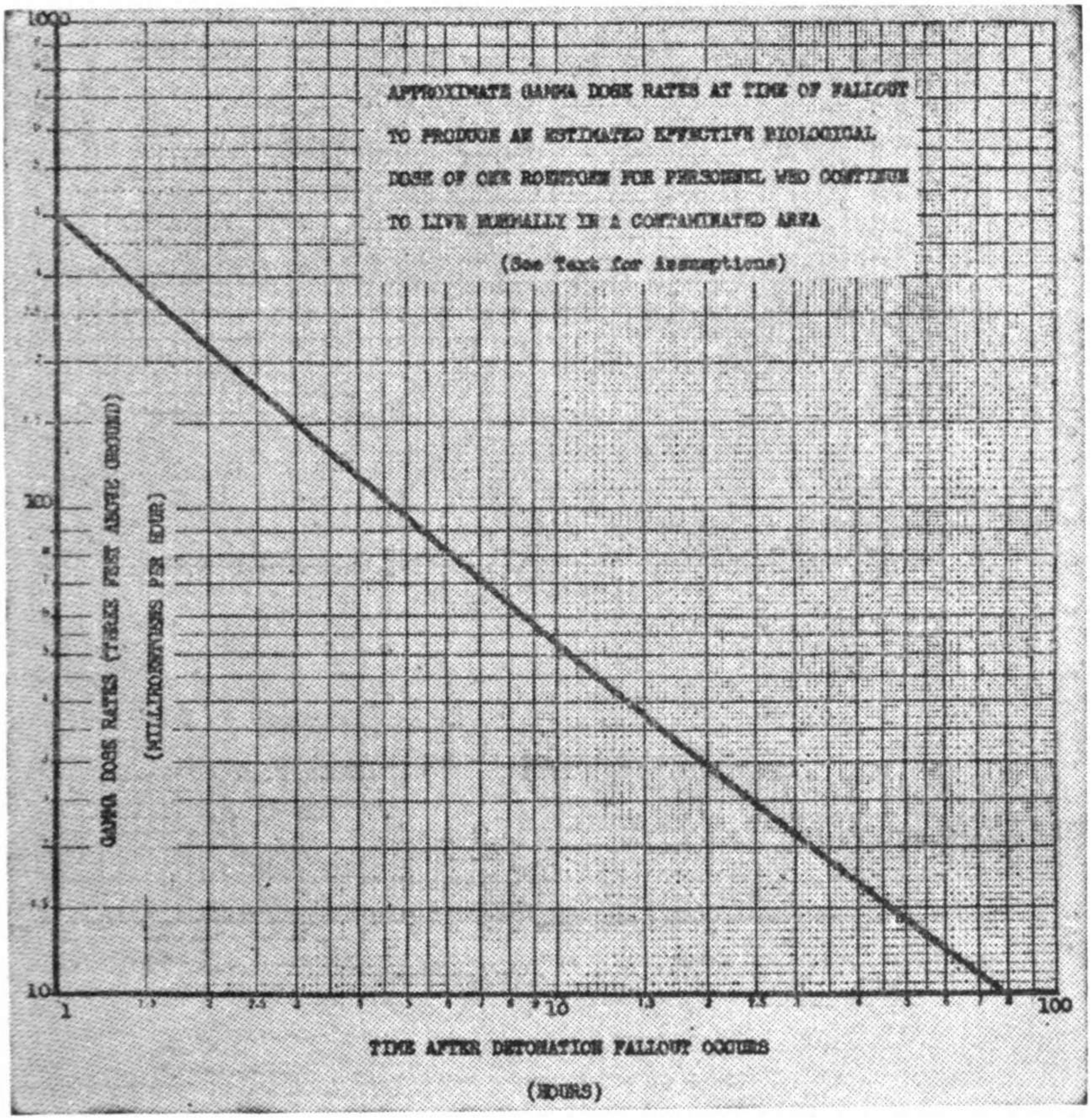


FIGURE 6



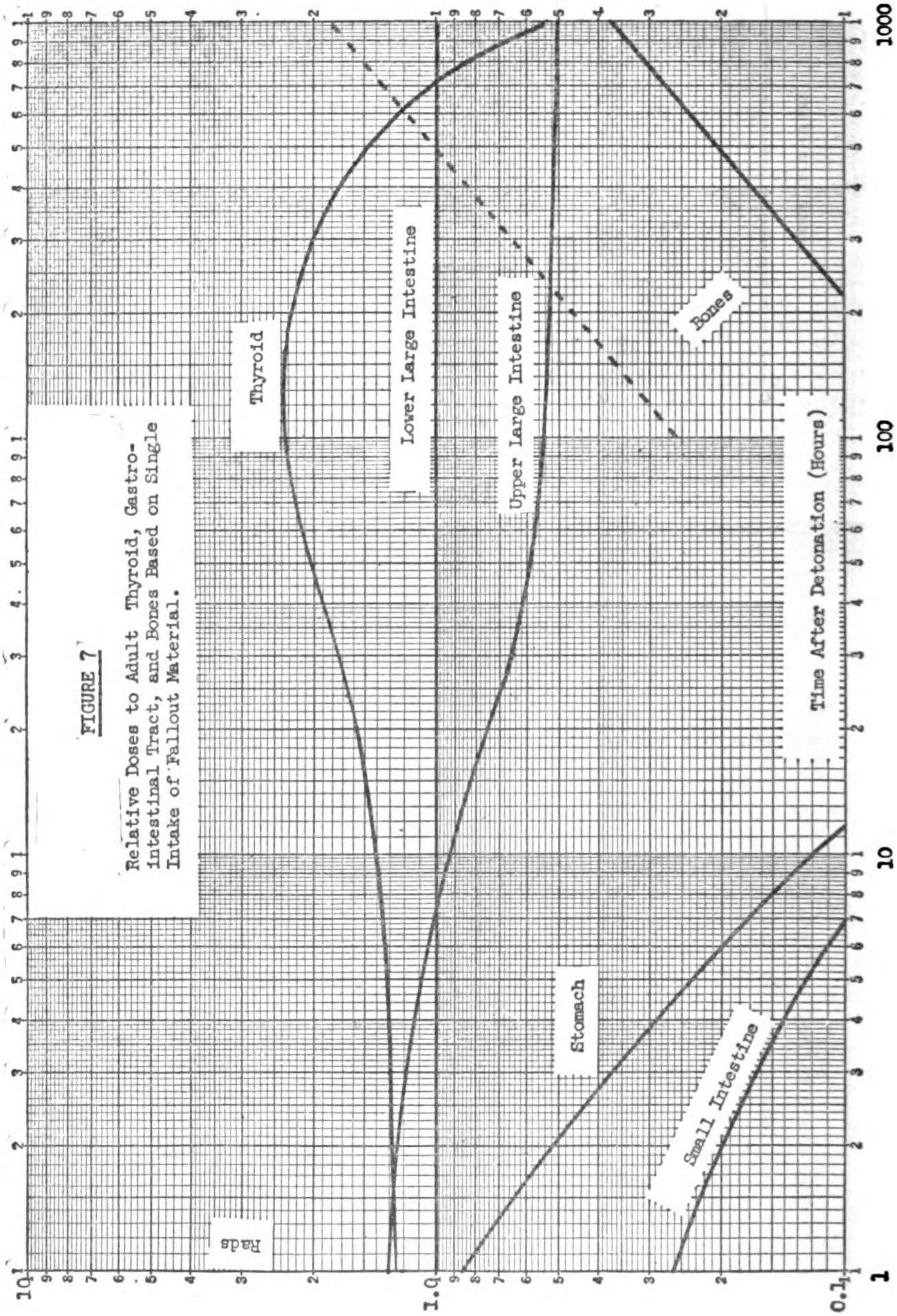


FIGURE 7

Relative Doses to Adult Thyroid, Gastro-intestinal Tract, and Bones Based on Single Intake of Fallout Material.

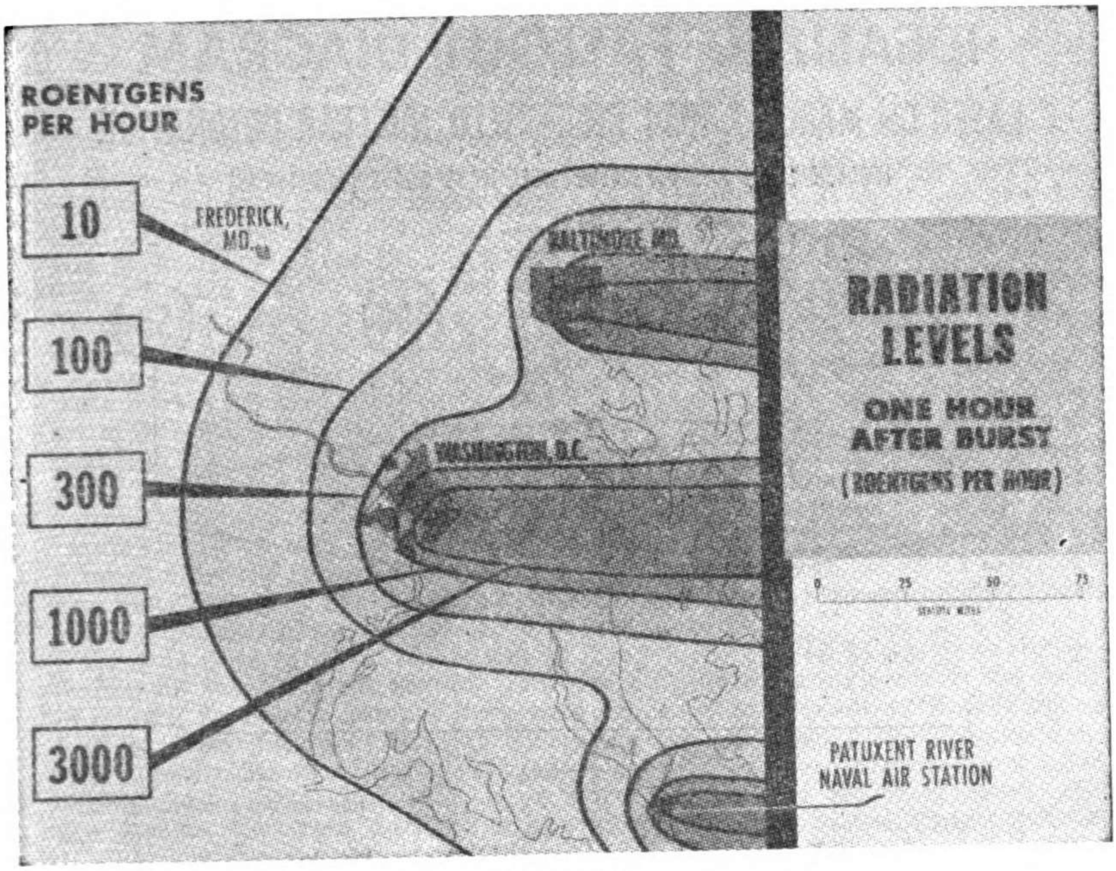


FIGURE 8

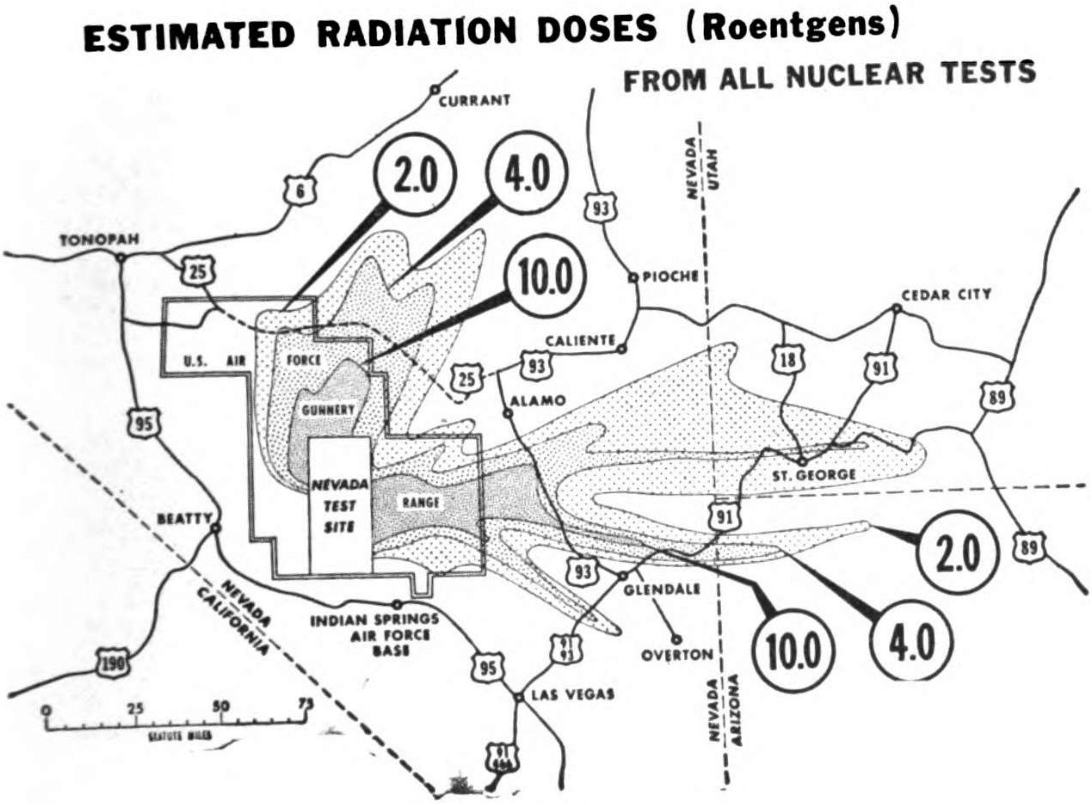


FIGURE 9

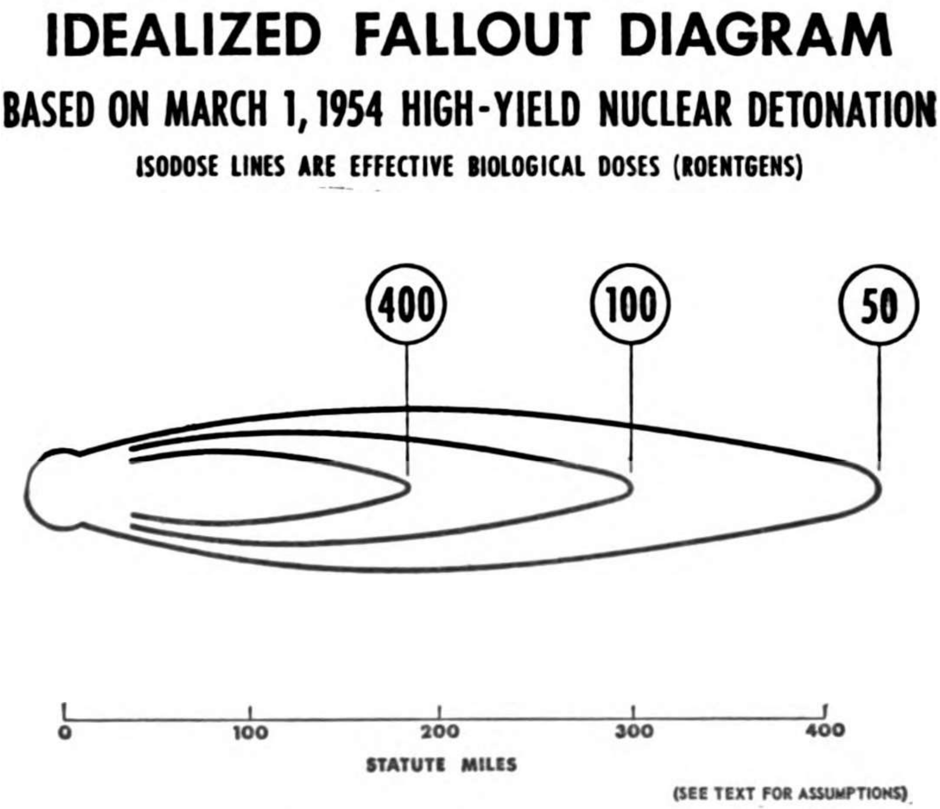


FIGURE 10. (See also table 3, p. 183.)

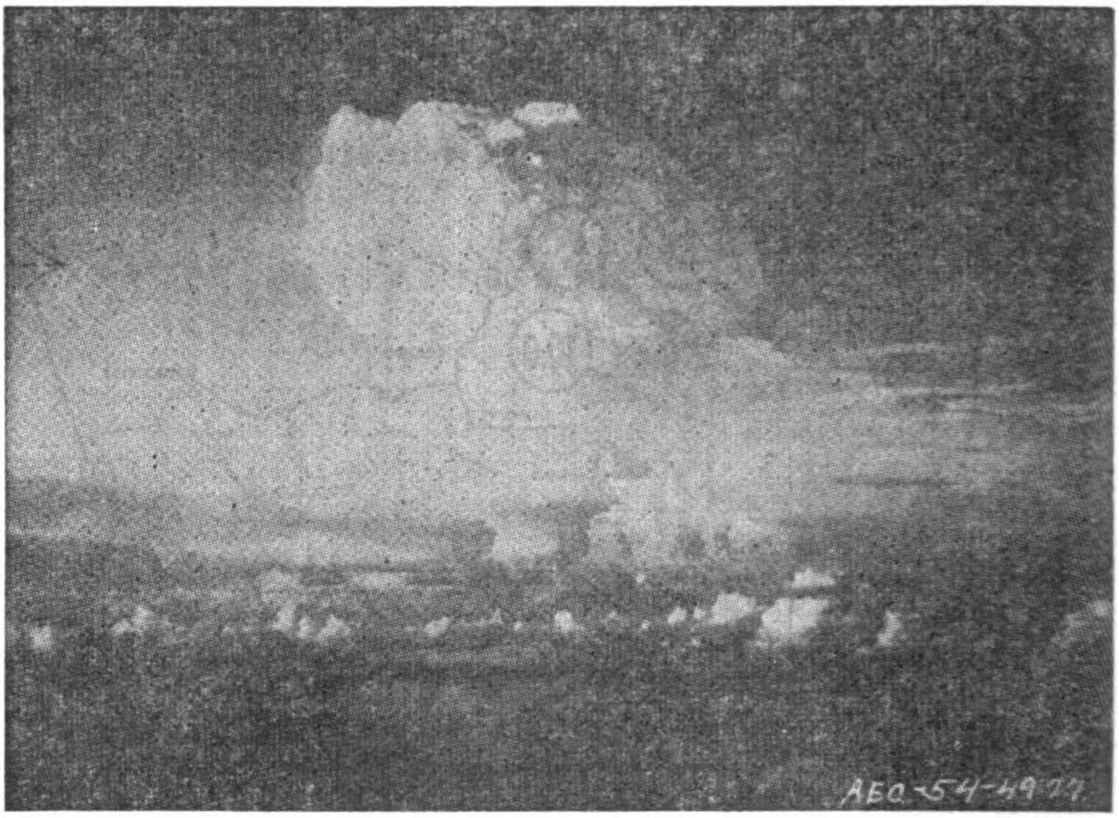


FIGURE 11.—Detonation during Operation Ivy; Fall 1952.

U. S. Atomic Energy Commission,
Washington, D. C., March 20, 1957.

Hon. Chet Holifield,
Chairman, Military Operations Subcommittee,
Congress of the United States.

Dear Mr. Holifield: This is in reply to your letter of February 25, 1957, requesting "(*a*) the roentgen readings on Rongelap Atoll as of January 1, 1957; and (*b*) the roentgen readings as of the same date on the downwind island of Bikini Atoll where the fallout might be expected to simulate that of a suburban area of a big city." We do not have the data in the exact form which you requested, but are glad to give you the following information concerning radiation levels in these areas.

The last survey which we made of Rongelap was at the end of July 1956. This survey showed dose rates ranging from 0.2 to 0.5 milliroentgens per hour with an average of 0.4 milliroentgens per hour. Previous surveys had indicated that the dose rates in July 1956 would be aboout 0.1 milliroentgens per hour. The higher value found in July 1956 was undoubtedly due to the small additional fallout that occurred during Operation Redwing. If so, because of the relatively rapid decay of this fresh radioactive material we would expect that at the present time the radiation level is again in the neighborhood of 0.1 milliroentgen per hour or less. This is about one-half the currently recommended maximum permissible rate of exposure for general populations.

Gamma dose rates on the island of Rongelap observed in previous surveys are shown on the attached graph. The plotted points through which the solid line is drawn represent gamma dose rate readings at a point of 3 feet above the ground. The break in the curve between the 10th and 25th day was undoubtedly due to the first heavy rains that were known to have occurred after the detonation. Aside from this break you will note that the observed decrease of the gamma dose rate during the first 2 years follows rather closely values predicted from theoretical considerations.

The gamma dose rates on other islands in Rongelap Atoll have not been followed as closely but the data indicate similar *rates* of decay with the most heavily contaminated island being about 12 times higher activity than Rongelap Island. This was the uninhabited island of Naen on the northwestern rim of the atoll. The decay rates have not been similarly followed on the islands of Bikini because additional fallout occurred on these islands from subsequent detonations during Operation Castle and again during Operation Redwing. It would be expected, however, if the rates of decay for the March 1, 1954, fallout could have been followed, they would have been somewhat similar to those shown in the graph. (See p. 192.)

For any single fallout event, the degree of initial contamination in any area depends upon many variable factors. In general, the data suggest that after March 1954. Also plans are being developed for a continuing and long-range and the corresponding radiation dose rate in close-in areas (i. e., 10 to 20 miles) are not greatly higher than at 100 miles downwind, under wind conditions of some 15–20 miles per hour. However, it is important to realize that the radiation dose received by unprotected persons in the close-in areas is greater because they would receive a substantial portion of their total dose during the time required for the fallout to reach the more distant areas. You will recall that the fallout on the island of Rongelap started at about 5 hours following the detonation.

The Atomic Energy Commission is currently preparing a report summarizing the data from the surveys that have been made in the Marshall Islands since March 1954. Also plans are being developed for a continuing and long-range program of monitoring these areas.

Sincerely yours,

David L. Shaw,
Assistant General Manager.

Dr. Dunning. In describing and evaluating the effects of fallout, it is necessary to consider the characteristics of the radiations emitted from the material. These are of three types, as you learned yesterday: Gamma rays, beta particles, and alpha particles.

The gamma rays are the emissions of principal concern, because of their greater range, and we will speak primarily of them.

The gamma radiation dose that one may actually receive from fallout, and the biological effects are dependent upon five principal factors. Let us consider each of these 5 factors briefly, and then attempt to integrate them into 2 illustrative examples.

The first factor is radiological decay.

The decrease in radioactivity of fallout material roughly follows the relationship of time to the −1.2 power.

I have illustrated on the first chart the doses that might be accumulated if fallout were to occur 1 hour after detonation. If you were standing out of doors, fully exposed, from the first to the seventh hour after the detonation, one would accumulate 32 percent of the total possible exposure in that area. From the seventh hour to 1 week later, 32 percent more, and from 1 week to the full lifetime of the radioactive material, the other 36 percent. This is based on a 1-hour fallout. (See p. 191.)

If the fallout occurs at later times, then the exposures accumulate much less rapidly. In other words, it would take much more than the first 6 hours to accumulate the 32 percent of the total possible dose.

The second principal factor that determines doses and effects is weathering and shielding effects.

Obviously, these vary from time to time and place to place, so we cannot make any precise evaluation of them, but we can make some generalizations.

Based on data from the Pacific tests, especially the one of March 1954, we found that the dose rates on the islands were reduced by a factor of about two after the first heavy railfall; but after that the subsequent rainfalls did not seem to reduce these dose rates appreciably. However, there are good data lacking on the effects of rainfall on relatively heavy fallout patterns for large land masses having different soil characteristics, or on built-up areas.

The next chart summarizes some of the estimates of shielding that might be expected from different type structures. These are based principally upon theoretical calculations, since there are a paucity of field data. (See table 1, p. 182.)

In an ordinary 1-story frame house, such as many of us live in, on the first floor there would be about 50 percent as much exposure as there would be out of doors. In the basement, the center, about 10 percent as much as that out of doors; on the side of the basement less than 10 percent; in other words, better protective factors.

For a multistory reinforced concrete, on lower floors away from windows, a factor of 10; and for the basement we are again down to one-tenth of 1 percent of the out-of-doors exposure.

Likewise, with shelter equivalent to 3 feet of earth, we are down to one-tenth of 1 percent of the outdoor exposure.

Senator HICKENLOOPER. Mr. Chairman?

Representative HOLIFIELD. Senator Hickenlooper.

Senator HICKENLOOPER. May I ask about the building, the frame house. Does that contemplate all the windows closed, or does it contemplate free access of air? Or is it in the blast area? Or where are these houses located, for the record?

Dr. DUNNING. The assumption is made here that the windows are closed. If the windows and doors are open, this in itself makes little difference, but then, as you implied this will allow the radioactive material to drift into the house, and, of course, raise your level.

Senator HICKENLOOPER. How does the radioactive material get into the house if it is a closed structure?

Dr. DUNNING. These are the actual gamma rays coming from the material lying outside, and they will pass right through the walls, and in doing so will be partly absorbed, but nevertheless in this case we estimate about half of them will get through the walls.

Senator HICKENLOOPER. Gamma rays coming from particles in the atmosphere?

Dr. DUNNING. That is right, sir.

Representative HOLIFIELD. There is a significant difference on the point that Senator Hickenlooper brought up, and that is that your gamma rays are rays which penetrate building materials in the one instance, but in the case where the windows have been blown out or the doors are open, the fission fragments can drift in and settle and emit the same type of rays without any shielding at all. Is that not true?

Dr. DUNNING. That is correct, sir.

One example of the effect of winds—one example of winds occurred at the detonation at the Nevada test site in 1953, when strong winds blew almost at right angles across a narrow band of fallout field on the second and third day after the detonation. The gamma dose rates on the fourth day were found to be less than predicted without winds by factors ranging from 3 to 6. In other words, the winds simply blew this material away, or it worked itself into the ground. But the effect of winds would not be expected to be as great as this for large contaminated areas of nonsandy soils.

The third factor that affects doses and biological effects is that of energy of these rays, discussed at some length yesterday. So I merely mention that the energy does determine the depth to which these rays will penetrate an object as large as the human body, and also the energy of these rays will determine the amount of energy that is released to the tissues in passing through the body.

It is quite a complicated process to try to estimate these various gamma spectra of the rays and to estimate their biological effects, but this is what is attempted when you say people receive so much dosage.

The fourth factor is that of geometry. That is, it is found if you have radiation coming from only a point and passing through the body from only one direction, as it passes through the dose will drop off within the body. Simply some of the energy is absorbed.

In the case of fallout, however, we have rays coming at you in various directions, sometimes all directions, and so we find then that the dose delivered within the body is almost uniform, that is, you get almost as much in the center of the body as near the surface.

The last factor in determining dose and effect is the biological repair factor. It has been recognized, in general, that the longer the period over which a given radiation dose is delivered, the less is the resultant biological effect, except for such aspects as genetic effects. In situations of heavy fallout and relatively large potential radiation doses, the biological repair factor may be considered in estimating incapacitating and lethal doses.

Representative HOLIFIELD. At that point, will you give us an explanation of what you mean by lethal doses, what type of cells in the body can be repaired, or be replaced, and what type of cells or parts of cells are permanently mutated?

Dr. DUNNING. It is not so much the question of the cells as the effect on the cells. As you intimated in the last part of your statement there, it is believed that genetic effects or mutations, whether it be mutations of the gene cells or the somatic cells, the living cells within the person, these effects are linear with dose. That is, if you double the dose, you double the mutations.

What I spoke of here was more the gross effect. In fact, I tried to indicate that when we speak about incapacitating and lethal doses, you ask yourselves the question: Is that man going to become so sick he cannot work? Is this man going to die? It is that more gross evaluation I had in mind when I spoke about biological repair, but there is a tremendous amount more to be learned on this factor.

Representative HOLIFIELD. You were speaking of the ability of the spleen to replace white corpuscles, and that sort of thing.

Dr. DUNNING. It is tied up very intimately with the blood picture, the production of white and red corpuscles.

Senator PASTORE. On this very point, how far have our experiments in Hiroshima and Nagasaki gone in proving some of the things you have just developed here?

Dr. DUNNING. I think there is experience in the Japanese data. I think we do have some other limited experiences where others have been accidentally exposed to relatively high doses. In fact, Dr. Graves described briefly his experience yesterday. And we do have evidence of this biological repair factor, especially, as I say, in the blood picture.

There is still a considerable amount to be learned in this, and I will not dare to go much further on this point at this time.

Chairman DURHAM. You are speaking just of the normal repair system, Doctor, by the body, and not by the addition of any medicines. or any type of treatment?

Dr. DUNNING. That is correct.

Senator PASTORE. Would you say that, comparatively speaking, we have not learned a great deal concerning this on experiments on animals in Hiroshima?

Dr. DUNNING. I would not say we did not learn a great deal. Quite the opposite. I will add, too, that every time you learn 1 thing, there seems to be 2 more to be learned. It just opens up whole new avenues of thought and study.

As you well know, most of our work has been done with animals, and then one is faced with extrapolating to man, and this is always uncertain.

Chairman DOUGLAS. Did you participate in that, Doctor?

Dr. DUNNING. No, sir; I did not. Our present knowledge does not permit us to establish a precise overall relationship for the rate of recovery and degree of recovery, but the data seems to indicate that the rate of recovery in man is relatively slow compared with animals.

Therefore, any biological repair factor would have its greater influence where a total given dose is spread out over time rather than the doses that are given rather quickly in time, such as nearby fallout.

Let us pass on, then, to the first of two examples.

One of them is an exercise during the National Association of Civil Defense Directors meeting in Washington, D. C., April of this year, where it was assumed that four bombs were dropped simultaneously, as follows:

A 20 megaton on the Union Station, Washington, D. C.; 5 megaton on the National Airport; 20 megaton on Baltimore, Md.; and 10 megaton on the Patuxent River Naval Air Station. The next chart will give a view of the resultant fallout pattern. (See top of p. 195.)

The units are in roentgens per hour, but in these nearby areas essentially all of the activity is down within 1 hour; so that this is a fairly realistic picture.

These are the numbers, such as 10 roentgens per hour and so on, to 3,000 roentgens per hour.

I would like to call attention especially to the 300 roentgens per hour line, since we will use this for an example in just a moment.

Recalling that radioactive decay is rapid for this early fallout around ground zero, it becomes evident, if adequate protective areas are available, it would be wiser for people to remain indoors, rather than be exposed out of doors, to the out-of-doors dose during this period of highest activity.

Likewise if a delay in movement is possible, there will be more of an opportunity to evaluate the situation, and to then effect an orderly evacuation.

Since each situation is unique, no rigid criteria will be proposed here for permissible exposures or for mandatory evacuation, since there may be other factors present as potentially hazardous as radiation.

This chart was developed to illustrate the kind of thinking and planning possible for civil defense. (See table 2, p. 183.)

Looking now at the 300 roentgen per hour line, we may permit our rescue workers 25, 50, or 100 roentgens, let us say. If we allow our rescue workers only 25 roentgens, that means for them to move into this area and do their rescue work and move out again, they will have to wait until 16 hours after the detonation before they may do so. In that length of time, the populace that were in this area would have received 320 roentgens, and this is based on certain assumptions. This is based on one assumption of rather small protective factors [indicating].

Before the populace is fully evacuated, they would have received 332 roentgens. On the other hand, if we allowed our workers to receive 100 roentgens exposure during the rescue work, they could have moved in at 5 hours instead of 16 hours, after the detonation, during which time the populace would have received considerably less exposure, this [indicating] being again the total exposure, before fully evacuated.

Looking at the last two columns, and especially the last one, it is based on the same situation; only in this case the populace is well sheltered. It is a factor of 10. We assume they are in good protective shelters. I say "good"—a factor of 10. It can be much better than this with well-constructed sheltering.

Even here I think this illustrates the point [indicating]: While they are awaiting rescue, they receive significantly less doses than in the less protected shelter. It is the same context of meaning. If rescue workers are permitted 25 roentgens, the populace will receive 76, as you note here.

Interestingly, if the rescue workers move in early and take the populace out of their relatively well-protected areas into the open, they may receive more exposure here than if they had stayed in place for

the full 16 hours. On the other hand, moving in at 5 hours may be a large advantage for first aid and rescue work, and this sort of thing.

Representative HOLIFIELD. Of course, this makes almost a conclusive argument on behalf of adequate shelter for the people, because, as you note there, if you take them out of the basement where they are getting a factor of 10 percent of the outside radioactivity, they must pass through an outside radioactivity which actually gives them an accumulation of radioactivity more than if they had stayed for, say, a week, in a shelter.

Dr. DUNNING. This is quite possible, although this is not my area of work.

Representative HOLIFIELD. Of course, it does not even compare with the amount the workers would get going into a contaminated area and coming out in a shorter length of time. They would get even more.

Dr. DUNNING. That is right.

Representative HOLIFIELD. That is right. It shows it at the bottom.

Dr. DUNNING. As I say, this is not my area of work. But it just seems to me, in case of emergency such as this, there would be such a chaotic condition that one of the worst things people could do would be to lose their heads and run out of doors, and, in a sense, run around in circles. It would be far better, if they have any kind of protective shelter, to stay put until they know what the situation is like, and then move in an orderly fashion.

Then, in essence, this sort of thinking and planning, I feel, will be most valuable rather than striving to establish any rigid rules or criteria ahead of time.

The second example of the dosage one may receive and the resultant biological effect is for a more distant fallout pattern.

As has been described by Dr. Kellogg and others, there is a wide variability in possible patterns; therefore we can only generalize again.

The next chart is again an idealized pattern. By that, we mean a generalized pattern, because conditions will change from day to day and situation to situation, but if we take a generalized pattern based on the March 1, 1954, high-yield detonation, we see a pattern like this [indicating]. These are expressed in units of effective biological doses, because these incorporate all of the five factors I mentioned briefly at the beginning. These are the best estimates of exposure that people would get if they continue to live in these areas without any special measures of protection. (See top of p. 196.)

Representative HOLIFIELD. What is the time element on that, Doctor?

Dr. DUNNING. Sir?

Representative HOLIFIELD. What is the time element? Is that per hour of exposure?

Dr. DUNNING. This is if they continue to live there for the lifetime of the activity, that is, a period of years, and took no special protective measures, merely went about their daily business. As you can imagine, there are certain assumptions that go into this as to how much time people spend indoors, in what type of buildings, and so forth.

Representative HOLIFIELD. Please repeat the numbers on your chart, because your testimony does not interpret the chart.

Dr. DUNNING. The 50-roentgen effective biological dose line extends out slightly beyond the 400 miles, and this area here [indicating] encompasses about 25,000 square miles.

The 100-roentgen line encompasses about half of that, 12,500 square miles; and the 400 roentgen line about 5,000 square miles.

This is suggestive of a number, 400 roentgens, where the people receive such an exposure that perhaps half would die. The 100 roentgen is suggestive where a few percent might become ill. The 50 roentgen line has no unique significance, but does suggest a number where evacuation should at least be seriously thought of in the face of other hazards.

For those areas downwind, where fallout occurs several hours after detonation, these doses will not be accumulated rapidly. In fact, it will be a period of months, or if you want to go to the end of the curve of doses, it would take a period of years before you would get this full dose. So it would not require immediate emergency measures downwind this far [indicating].

The question is frequently asked as to the time one must spend within a shelter or remain outside of a contaminated area. Again, the answer depends upon what are the permissible levels of exposure, and what are the other hazards one faces if he does move out. But it does indicate that even in the areas of heaviest contamination that one may move in and do a short rescue work, and move out again, if you are willing to permit relatively high exposures to your rescue crew in the order of 100 roentgens.

One then asks the question, How long would I be denied this area? How long before I can go back in there to live?

We assume now they have been moved out. How soon may they move back?

Just taking 4 months later as a point of reference, at 4 months how would this picture look then?

Again, based on certain assumptions, this 50-roentgen line would have shrunk down to an area of about 2,500 square miles, meaning if people move back in here 4 months later and continue to live there indefinitely thereafter in a normal fashion, then they would accumulate about 50 roentgens, effective biological dose.

Then you may extrapolate still further and say, "How about 1 year later? What will this pattern look like then?" Again, it is quite uncertain. But based on certain assumptions again, the 50 roentgen line would have disappeared. In other words, there would be no area in here where people would accumulate 50 roentgens of exposure if they move back in 1 year after the fallout and continue to live there indefinitely.

This does incorporate the biological repair factor, but there are such effects as genetics, as I mentioned, that are linear. In this hottest area it is conceivable there could be several hundred roentgen doses delivered to people who move back in there 1 year later and continue to live there normally.

As I said before, the biological repair factor would bring this down below 50 roentgens, but in terms of genetics, and such aspects, the actual dosage might be several hundred roentgens.

Representative HOLIFIELD. Then this would mean that large areas of land might remain unoccupied for a considerable number of months?

Dr. DUNNING. Yes. But I was about to mention that this is based on the assumption that people do nothing to protect themselves, and nothing to decontaminate the area; simply let it lie there and decay.

Representative HOLIFIELD. It is a very difficult job to decontaminate the large areas of the earth.

Dr. DUNNING. That is quite true. Probably one of the best procedures, if one can afford to do this, is merely to wait and let the activity decay away. But in this area of highest activity which would encompass, perhaps, a few thousand square miles, perhaps measures could be taken on decontamination which would not have to be done in the larger 25,000 square mile area.

Senator BRICKER. What processes of decontamination are available?

Dr. DUNNING. This is a whole subject in itself, sir. I will just briefly mention that the United States Naval Radiological Defense Laboratory in San Francisco have made considerable studies on this subject, and have proposed certain measures of decontaminating buildings and land areas. How effective they are I think is yet to be shown. There has been some experimentation, but I feel a great deal more needs to be done.

Chairman DURHAM. You are speaking primarily to gamma rays now; are you not?

Dr. DUNNING. Yes; this has been completely on gamma rays.

There are other types of rays. The beta rays are of concern, it appears, according to our present data, only when the fallout material comes directly on the skin and remains there for a period of time.

In the case of the fallout of the Marshallese, it was very illuminating to note that even a single layer of cotton clothing was enough to prevent serious beta dose to the skin, and where the fallout material did land on the skin and did remain there, such as in the folds of the neck and in the elbow, there were these so-called beta burns, burns of the skin from these beta rays. Yet, where they had the light clothing on, there were no burns. Nor were there any on even the lower part of the leg, but there were on the feet where again the material had been scuffed up from the ground.

Representative HOLIFIELD. Can you refresh the committee's memory on how many days later this exposure occurred, and how far the place was from the point of detonation?

Dr. DUNNING. The inhabitants of Rongelap Island were about 110 statute miles from the point of detonation. Some were evacuated at 36 hours, and some at about 48 hours after detonation. Upon evacuation, they took baths. Some of them did beforehand, and some of them not. It would appear that those who did take baths in the ocean did not get beta burns. It is merely a physical picture of moving the material from the body.

Representative HOLIFIELD. I referred to that specifically, and I am glad you answered the way you did, because this gives you a chance to answer also in regard to the Japanese fishermen on the *Lucky Dragon* as to how many days later it was they were supposed to have received their exposure.

Dr. DUNNING. They were generally in the same distance, only somewhat closer than the Rongelapese. The fallout occurred on

them, and they did not wash in general. Most of the dose was delivered in the first few days, and so it is a question of getting it off and getting it off fast.

The next topic we will discuss is that of internal exposure which has been mentioned several times before this committee.

The principal hazards from intake of relatively large amounts of radioactive fallout for several weeks immediately following a nuclear detonation are doses one may get to the gastrointestinal tract, to the thyroid, and to the bones.

My written report to this committee considers in detail the amount of ingested fission product activity material required to produce certain radiation doses to these critical organs of the body, and the possible biological effects therefrom.

It is a somewhat long, complicated story, Mr. Chairman, and I would let it go at that, and quote one conclusion, and that is: If the degree of contamination of an area is such that the external gamma radiation may be accepted, for continuous occupancy, then probably the internal hazard would not deny this occupancy.

I think some folks get somewhat confused. They say: "Fine. I think I begin to understand the external doses, but should I drink this water? And should I eat this food?"

As I say, as an overall generalization, this conclusion would appear to be so, but like most of these it is tentative and awaits further information.

Representative HOLIFIELD. There is this one factor I think you will recognize: That in the ingestion of material from the secondary source of vegetables or milk, you would be ingesting the long-lifed element of strongtium 90, and not the comparatively short-lived gamma or beta rays.

Dr. DUNNING. That is correct, sir; and my conclusion took that into account.

Representative HOLIFIELD. Of course, while it might not be lethal, and would not be lethal in the quantities you speak of, it would be residual within the bones or the tissues of the body, and would be a permanent infestation, you might say.

Dr. DUNNING. That is correct. But then one must go from there to the next step, and say, "What is the actual dose delivered to the bones from this internally deposited material?" Because actually there is no significant difference between a roentgen of exposure, whether it comes from strontium 90 or from gamma rays, coming from material lying on the ground.

That is what I put into this conclusion when I said the amount of material that one gets into the body by eating food and drinking water in such an area would be acceptable in the sense that it would be far below lethal amounts. But I think we have to make a distinction in our mind here between peacetime tolerance levels and wartime. I do not have any specific number in my mind, but in these areas where we might permit occupancy in the case of warfare, they would probably accumulate internally deposited materials that would be in excess of our peacetime standards. I think we have to make this distinction.

Representative HOLIFIELD. Is there a distinction between an area that has a hundred roentgens of gamma radiation and its effect upon

the body and, say, the ingestion of 5 or 10 roentgens which remain permanently in the bone now?

Dr. DUNNING. There is very little difference between a roentgen delivered from internal or external sources.

I think, in general, one can make the flat statement that a hundred roentgens, whether it comes from material on the ground or in material you eat, and that goes to the bones, is about the same.

Representative HOLIFIELD. It is a hundred roentgens, but it is not a deposit of strontium 90, which has a persistence over a period of 28 years, while your outside exposure, you might say, to gamma rays or beta rays, would be something that would be temporary in nature and would be subject to repair, where a permanent deposit in the bone marrow would be permanent as far as the half-life is concerned; and, therefore, it would be something that you could not get away from, you might say.

Dr. DUNNING. Yes; I understand. I just repeat that, if we forget the time factor for a moment and simply say that so many roentgens of exposure to the bone, it makes no difference whether you get the hundred roentgens from the gamma rays or from the material in the body. It stays there. Sure, it persists there. What I was saying, as long as it persists, we have the doses year by year by year, and if it all adds up to a hundred roentgens, this is no different, in a sense, from a hundred roentgens of gamma rays, except possibly for the time factor.

Representative HOLIFIELD. This is getting in pretty deep water for me. My thought was that you have a permanent localized area of radiation in the ingestion of strontium 90, where you would not necessarily have a localized concentration of it in the case of allover bodily exposure of a hundred roentgens.

Senator BRICKER. I think there is a misunderstanding generally about the amount of strontium 90 that can be put in the bones from ingestion, because there is only a small percentage of fallout of strontium 90 that goes to plantlife, and only a limited percentage of strontium 90 that goes to animal life, and only a little percentage of that which goes into milk or meat. I think it is something like 6 percent.

Dr. DUNNING. If I may move on, that was my next point here.

Again now we are thinking in terms of warfare, and not in terms of testing.

We have the situation of this March 1 shot, where we have a relatively heavy fallout from a high yield weapon that appeared on the islands in the Pacific. Since then, we have had 10 radiological and biological surveys of these islands. I thought the committee would be interested in a summation of those data, that is, what was the actual contamination of environment in terms of food supply.

I would like to preface by saying that any conclusions are tentative because there are many uncertain factors here, but at least the data suggests in terms of strontium 90 the activity in plantlife in these islands built up over 1 year, that is, it takes time for material to get into the soil, plantlife, and edible parts.

By using rough extrapolations, the data suggests that if plantlife had been growing in the area of heaviest contamination it might have contained 10,000 to 30,000 Sunshine units, at 1 year's time. The corresponding values for the soils are several times higher. Based on

certain assumptions, these data suggest possible levels of strontium 90 in the bones of animals from continuous consumption of this food, of a few thousand to several thousand Sunshine units. Now the maximum permissible body burden for adult atomic-energy workers is equivalent to 1,000 Sunshine units.

There is some confirmatory evidence for this crude evaluation. A variety of native animals were left on the island of Rongelap after the fallout in March 1954. They were collected and sacrificed serially in time. Even after 2 years of continuous occupancy it was reported that there were no pathological changes that could be ascribed to radiation. Their bones contained from about 100 to a few hundred Sunshine units. Since the areas of highest contamination were about 12 to 14 times greater than Rongelap, an extrapolation would suggest values in the same range, that is, if animals had lived in the area of greatest contamination from this fallout, they might have accumulated from a few thousand to several thousand units, of strontium 90 in their bodies.

The Pacific island soils have higher calcium content than most soils in the United States, and, of course, there are differences in the type of plantlife and in the climate. However, theoretical calculations suggest that the same fallout in the United States might result in something like 100,000 Sunshine units in the soils of the United States with the highest contamination. Humans living exclusively off the foods grown in these soils might accumulate a body burden of strontium 90 of a few thousand to several thousand Sunshine units, keeping in mind that 1,000 is the maximum permissible body burden for atomic-energy workers.

Chairman DURHAM. Doctor, the effect of a hundred roentgens from the soil would be no more toxic than the 100 roentgens from the strontium; is that correct?

Dr. DUNNING. As far as the bones are concerned, it is correct. If you receive 100 roentgens from the gamma or strontium, it is essentially the same thing.

Chairman DURHAM. I was thinking of gamma rays.

Representative HOLIFIELD. Let me ask this question on that very point: If the 100 roentgens were ingested, would they not tend to go to certain organs of the body and have a concentrated effect, and, therefore, more of an effect upon, let us say, the liver or the spleen, or some other organ of the body that might be vital to the life of a man, than if the 100 roentgens were spread over the whole body?

Dr. DUNNING. If you could turn that around just a bit, Mr. Chairman. The way we compute it, we asked the question, How much material taken into the body will essentially result in 100 roentgens to the bones, to the liver, et cetera? We start the other way around from what you are saying. We simply ask how much material does one have to take in to end with a 100 roentgen dose. So we have reached our conclusions——

Representative HOLIFIELD. Again, are you not faced with the fact that you could not give a uniform dose of a hundred roentgens to every organ in the body, because some organs of the body—and I am speaking now in the case of ingestion of food or drink—some of the organs of the body would naturally process that, and it would be deposited in those organs rather than in the outside skin and toenails, and so forth.

Dr. DUNNING. That is correct. When we speak of external gamma, we mean essentially that each and every part of the body receives this 100 roentgens.

Representative HOLIFIELD. This I can understand, but I cannot understand how you can ingest contaminated foods or liquids and have it affect the body uniformly.

Dr. DUNNING. I did not mean to say that. If I did, it is incorrect.

Representative HOLIFIELD. You did not say it. I am saying it as a question or a statement for clarification.

Dr. DUNNING. You are quite correct.

Representative HOLIFIELD. Am I right in my supposition?

Dr. DUNNING. You are quite correct.

Chairman DURHAM. What we are saying, Doctor, whether it comes from Sunshine or whether it comes from strontium 90, that is, the gamma ray, it is no different as far as the effect of it, as if the same dose is taken.

Dr. DUNNING. That is correct, sir.

Lastly, then, I would like to mention briefly about the testing, and I do think we have to make a sharp demarcation in our minds that we have up to now been talking about more of a warfare situation. But intimately tied up with this is the testing.

Very extensive efforts are expended to protect the public in the planning of test nuclear detonations, and in the monitoring programs in operation during and between the test series. These are described in a detailed written report to the committee previously.

Since 1951, the United States has conducted 11 series of nuclear tests, 5 at the Nevada test site, and 6 at the Eniwetok Proving Ground for a total of more than 63 test detonations. A sixth series is currently underway at Nevada. So I understood by the report this morning.

The major effects near the testing sites of the fallout was on the inhabitants of some of the Marshall Islands in March 1954, which will be discussed by others, and fallout on the 23 Japanese fishermen. Worldwide effects will be discussed by others.

Since the committee manifested an interest yesterday in the fallout nearby, especially in Nevada, I do have a chart that may be of interest to you. This is our best estimate of exposures in areas around the Nevada test site. The units are roentgens of gamma exposure. They are based on certain assumptions, one of which is that the total dose is this [indicating] if one continues to live there indefinitely. (See bottom of p. 195.)

With those numbers before you, I would like to recall to your mind the recommendations of the National Committee on Radiation Protection and Measurement, and the recommendations of the National Academy of Sciences, which, in lay language, sort of lays the ground rules for our permissible exposures.

Both committees—expressed in somewhat different units, both committees said, in essence, that for individual exposures the maximum permissible amount should be 50 roentgens up to age 30.

Representative HOLIFIELD. At this point, it might be well for you to explain the term "Sunshine unit" in relation to roentgen. Is that not an occupational unit of measurement rather than a general population unit of measurement?

Dr. DUNNING. The Sunshine unit is a coined phrase which is used to express the amount of strontium 90 in relation to the amount of calcium, whether it be in the bones of man, or in the soil or anywhere else. Just like when one buys milk, you have to have some unit. It is merely a coined unit so that one in this business may know how much strontium 90 you are taking about when you say 1 Sunshine unit.

Representative HOLIFIELD. It is not to be confused with a roentgen?

Dr. DUNNING. That is correct. One could mathematically figure out the amount of roentgens 1 Sunshine unit would produce, but it is not the same.

These again are not Sunshine units; these are the more familiar roentgens that we have recently spoken about. So again we say that the maximum permissible exposures for individuals is 50 roentgens up to age 30.

Now, for general populations, which one may define as a million people or more, the maximum exposure from manmade sources, the maximum number recommended is 10 roentgens up to age 30.

So we have for individuals 50 roentgens, and for general population, 10 roentgens up to age 30.

Now, let us look at the records of exposure to populace in these areas.

The highest fallout exposure was in this motor court near Bunkerville, Nev., in 1953, where the people might have accumulated 7 to 8 roentgens of exposure. This might rightfully be compared to the 50 roentgens that I mentioned before as a ground rule.

In terms of general populace around the Nevada test site, I had a little problem finding a million people for a general population, but if one mentally makes larger and larger circles until he encompasses a million people, then the average exposure to the 1 million, is one-tenth of a roentgen for 6 years of testing, which is at the rate of one-half a roentgen per 30 years, which is one-twentieth of the maximum exposures recommended by the 2 committees.

Representative HOLIFIELD. This would be on one test?

Dr. DUNNING. These are all tests. I am sorry.

Representative HOLIFIELD. This is the accumulation of all tests?

Dr. DUNNING. This is the accumulation from all tests; not only Nevada, but all others. This is the sum total.

Lastly, on air and water concentrations, the internal exposure side of the record, I would say this: The highest concentration of activity in the air off the test site in the spring of 1953, the Nevada test site, amounting to 1.3 microcuries per cubic meter of air averaged over a 24-hour period. It was estimated that the radiation dose to the lungs from this activity was less than that delivered every month by naturally occurring radioactive isotopes in the air that we breathe every day.

Representative HOLIFIELD. That is based on an average, but not necessarily a hot spot locality?

Dr. DUNNING. This was the highest concentration of air found in any populated area. There are higher concentration spots on the gunnery range, the control area.

Representative HOLIFIELD. When you speak of normal does that mean sunshine?

Dr. DUNNING. When I said the doses to the lungs?

Representative HOLIFIELD. Yes.

Dr. DUNNING. In this room, right in this air, there are naturally occurring radioactive materials. Every time you breathe in you get a certain radiation dose to your lungs.

What I was saying, then, was that by living normally over a period of a month, we have a certain dose delivered to our lungs from this naturally occurring material. Then I compared that with the people who were in this area where the fallout occurred, and said they breathed in the fallout, and then asked how much dose did they receive to the lungs from the fallout. And that is when I made the comparison that the dose from the fallout was less than they would have received each month from breathing naturally occurring substances.

Senator BRICKER. That is background radiation principally?

Dr. DUNNING. That is correct.

Senator BRICKER. Have you anything to say about the effect upon the length of life? I ask that because of animal experimentation. Is there any indication that radiation does shorten life?

Dr. DUNNING. This is again a topic in itself. I am not an authority on it, and would prefer to leave it to those who follow.

Senator BRICKER. I am advised again there is a witness later.

Dr. DUNNING. I think, again, one has to distinguish, though, between chronic and acute doses. There apparently is a significant difference in life shortening effect in large doses delivered in a short period of time versus low doses over a long period of time.

Senator BRICKER. Even though there may be some effect from each?

Dr. DUNNING. There may be some effect from each. I would leave the conclusion to others on that.

Lastly, how about the water contamination?

Once again, the record says that the highest concentration of activity in water off the controlled area was at Upper Pahranagat Lake, Nev., in the spring of 1955, amounting to 1.4 times 10 to the minus 4 microcuries per milliliter at 3 days after the detonation. This is one-thirty-sixth of the amount considered safe for continuous consumption.

Representative HOLIFIELD. Doctor, referring back to your statement on the Riverside motel cabin, what did you say their exposure was there?

Dr. DUNNING. Estimated exposure to people, if continued to live there, was 7 to 8 roentgens.

Representative HOLIFIELD. We have in the committee record a document prepared in February 1955 by yourself, in which you say:

> In the case of Riverside Cabins, however, the radiological conditions were not ascertained until after the fallout had occured. The maximum infinity gamma dose in the later case was 12 to 15 roentgens.

Have you revised your opinion, or how do you reconcile your two statements?

Dr. DUNNING. No, sir; I have not revised it. It is the difference in units. The infinity exposure is on the assumption that people live out of doors 24 hours a day, that there is no effect of weathering and shielding, that the material lies there, neither is lost by wind nor rains, nor does it sink into the ground.

We went back and made a study of that area and of the shielding effects of the homes and of the weathering, and were able to take a series of measurements of dose rate readings, with times, and by this we came up with this estimate of actual exposure of 7 to 8 roentgens. So the difference is in the units. Infinity does mean where they could

not have been any higher than this. In other words, we were giving outside limits, and a complete analysis of the situation led us to believe that the actual exposure would have been 7 to 8 roentgens.

Representative HOLIFIELD. Thank you very much.

Are there any further questions?

We have about 5 minutes. We have a few questions, Dr. Dunning.

If weather and terrain factors cannot be generalized, how reliably can one evaluate the situation at any particular locality? What information do we need to make such evaluation?

Dr. DUNNING. I did not hear the first part, Mr. Chairman.

Representative HOLIFIELD. If weather and terrain factors cannot be generalized, how reliably can one evaluate the situation at any particular locality?

(Discussion off the record.)

Representative HOLIFIELD. Dr. Dunning, will you please answer the question now?

Dr. DUNNING. From a precise scientific point of view this is certainly questionable. However, I think we are faced with the problem of either making our best estimates for planning purposes, or making none. It is on that basis that we have made our best estimates. We simply have said we know something about the effects of winds, we know something about the effects of rains; we will, therefore, try to generalize on what they might be under certain situations.

I do not think anyone is guaranteeing that they will be precisely this way in the case of an actual situation, and the same is true with terrain factors. Again we know some effects of terrain factors. We know the shielding effect of a hill, for example, and the unevenness of the ground as it affects the radiation exposure. Again we must generalize for planning purposes, or not generalize at all. I think that is our choice.

Representative HOLIFIELD. Dr. Dunning, due to the time, we are going to have to adjourn. I am going to hand you three questions here which I would like for you to prepare answers to, and then we will insert them at the conclusion of your testimony.

Dr. DUNNING. I would be delighted to, sir.

(The questions and answers referred to follow, together with a discussion of radiological safety criteria and procedures for public protection at the Nevada test site:)

Question. How was the 450 roentgens lethal dose figure established? What is the range of competent opinion on this number?

Answer. The lethal dose values for humans has been developed primarily from the Japanese data, plus extrapolations from animal experiments. The range of values for LD-50 values (half the people so exposed would die) are roughly from 375 to 650 roentgens. But this range is not as great as these figures might imply. As I have suggested a roentgen of dose as measured in air may deliver different doses within the body, depending upon the geometry of the source. That is, if the radiation is coming primarily from a point source such as the immediate radiation at time of burst, the radiation doses within the body will decrease as the rays pass through. On the other hand in the case of fallout the rays are entering the body from several directions and thus the doses will be more uniform within the body. Under this second set of conditions a lesser number of roentgens as measured in air could produce lethality. The 375 roentgens was estimated on the basis of fallout conditions while the 650 roentgens was for the immediate radiations from the burst.

Question. How constant is the relation between air dose and the biologically effective dose in view of the known gamma radiation energy changes with time?

Answer. It is correct that the energy spectra of gamma radiation dose changes with time and thus will affect the dose distribution within the body and the energy delivered to different parts of the body. Further, the energy spectra at any one time is quite complex, consisting of photons over a wide range of energies, except for long times after a detonation when only a relatively few isotopes remain, such as cesium 137. All of these do complicate the problem of estimating the biological effects. However, there are other variables, such as weathering and shielding and decay constants that have as great or probably greater influence in determining the effective biological dose accumulated.

Question. Compare the numbers derived from the $(\text{time})^{-1.2}$ law decay with that derived from the application of the known gamma emissions from the fission products.

Answer. The relation of $(\text{time})^{-1.2}$ was intended to apply to the actual disintegrations of the atom. We have accepted the rate of beta emissions as closely approximating the actual disintegrations of the atom. However, the ratio of gamma photons emissions to beta emissions varies with time (as does the gamma energies) so that the actual decay of *gamma dose rates* can deviate from the $(\text{time})^{-1.2}$. This deviation probably is not very great until several months after the detonation, when theoretical calculations indicate that the decay is significantly greater than $(\text{time})^{-1.2}$. This is shown in figure 4 of my written report. Of course, presence of any *induced* activity can also result in a departure from $(\text{time})^{-1.2}$.

Discussion of Radiological Safety Criteria and Procedures for Public Protection at the Nevada Test Site *

Gordon M. Dunning, United States Atomic Energy Commission, Division of Biology and Medicine, Washington, D. C., February 1955

INTRODUCTION

The criteria and procedures set forth in the following paragraphs were established after full consideration for protecting the health and welfare of the public, both in terms of radiological exposure as well as possible hazards, hardships, or inconveniences resulting from disruption of normal activities. Criteria are established as guides for the test organization in determining whether any special actions should be taken to protect the public.

With improved methods of predicting fallout and with the use of higher towers for detonating the nuclear devices, it is expected that fallout in populated areas from future tests at the Nevada test site will be less than the highest amounts which have occurred in the past.

Two basic assumptions are made in this report:

(*a*) It is the responsibility of the Division of Biology and Medicine to establish such criteria and procedures for the Atomic Energy Commission as deemed necessary to protect the health and welfare of the general populace from consequencies of weapons tests conducted at the Nevada test site.

(*b*) The operational procedures adopted for meeting these criteria and procedures shall be the responsibility of the test manager, as directed by the Division of Military Application, with the technical guidance of the Division of Biology and Medicine.

The following criteria do not apply to domestic or wild animals since levels of radiation which would be significant to them would have to be higher than those specified herein.

CRITERIA I. EVACUATION

Introduction

The decision to evacuate a community is critical for two principal reasons: One, presumably there might be a health hazard if the personnel were allowed

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* This document was based on data and thinking of nearly 3 years ago. Since then the criteria have been revised and are reproduced on pp. 248 through 258. It is planned to revise further these criteria based on additional data and experience gained from operation PLUMBBOB (1957 test series at the Nevada test site).

to remain. Two, there is always an element of danger and/or hardship to personnel involved in such an emergency measure.

It is recognized that extenuating circumstances may accompany any situation where conditions indicate evacuation as a mode of action. The size of the community, areas, and accommodations available for the evacuees, means of transportation and routes of evacuation, disposition of ambulatory cases, protection of the property left behind, and many other factors may enter into the decision relative to evacuation. Further, it is recognized that, under certain conditions, the evacuation of a community might not only prove rather ineffectual but could result in more radiation exposure than if the population remained in place unless the situation be adequately evaluated. A blanket evaluation cannot be made in advance; each situation can be unique. The following criteria therefore are suggested as guides in assessing the possible radiological hazards; the final decision must be made on the basis of all relevant factors known at the time.

Criteria

Table I–a summarizes the radiological criteria to be used in evaluating the feasibility of evacuation.

TABLE I–A.—*Radiological criteria for evaluating feasibility of evacuation*

Effective biological dose [1] calculated to be delivered in a 1-year period following fallout	Minimum effective biological dose that must be saved by act of evacuation (otherwise evacuation will not be indicated)
Up to 30 roentgens	No evacuation indicated.
30 to 50 roentgens	15 roentgens.
50 roentgens and higher	Evacuation indicated without regard to quantity of dose that might be saved.

[1] The "effective biological dose" is an estimate of a biological "damage" dose, taking into account the length of time for delivery of a given dose, and the reduction of dose due to (*a*) shielding afforded by buildings and (*b*) the process of weathering.

The rationale for table I–a is as follows: The total effective biological dose that would be received if evacuation were not ordered is obviously a determining factor. Another consideration is the fact that such an action as evacuation could be dangerous to the individuals and could also possibly be detrimental to a very necessary national effort of weapons development. One must then ask, "Just how much will be gained (radiation dose saved) by evacuation?" Estimates of these two variables are indicated in table I–a. Thus, a populace may receive up to a calculated 30 roentgen effective biological dose in 1 year without indicating evacuation; from 30 to 50 roentgens, evacuation would be considered only if at least 15 roentgens could be saved by such action; and at 50 roentgens or higher evacuation would be indicated without regard to the possible savings in radiation dose.

In making a rough estimate of radiation doses, one may calculate a theoretical maximum infinity gamma dose and then arbitrarily divide by some number, such as 2, for an estimate of dose actually received. Whereas this may be satisfactory as a first approximation, a more accurate estimate should be attempted, especially when dealing with doses that might constitute a health hazard.

Owing to the necessity of making early measurements and decisions, it is to be expected that dose-rate readings, taken with survey meters, will be available evidence at the times of concern. Table I–b summarizes the parameters considered in estimating an effective biological dose based on dose-rate readings.

TABLE I–B.—*Predicting effective biological doses from dose-rate readings*

	A Theoretical maximum dose (based on best estimated rate of decay)	B Biological factor	C Attenuation and weathering factor	D Effective biological dose factor (column B×C)	E Effective biological dose (column A×D)
From time of fallout until time of evacuation	----------	1/1	1/2	1/2	----------
From time of evacuation to time of return [1]	----------	3/4	3/4	[2] 1/2	----------
From time of return to a time 15 days after initial fallout [3]	----------	3/4	3/4	[2] 1/2	----------
From 15 days until 1 year after initial fallout	----------	2/3	1/2	1/3	----------
Total	----------	----------	----------	----------	----------

[1] This estimate is based on the concept that if evacuation were not accomplished, then a certain radiation dose would be accumulated over the period of time selected. This time period also represents the radiation dose saved if evacuation were accomplished.

[2] The value of 9/16 has been rounded off to 1/2.

[3] This assumes that the time of return occurs before 15 days. A period of 15 days was selected to provide a dividing point between the time of initial exposure from fallout to a time 1 year later. The 15 days has not unique significance other than providing a basis on which to estimate the biological factor.

At a later time after fallout, better estimates of radiation doses received may be obtained from film-badge readings or dosimeters. If these film badges or dosimeters are worn on personnel and the evidence of their use supports the view that the readings are a reasonably accurate account of the radiation dose received, then the values recorded on the film badge or dosimeter may be accepted with a correction factor of 3/4 to account for the difference between the dose received by the film badge or dosimeter (including back scatter) and that received at the tissue depth of five centimeters. Table I–c may be used in estimating the effective biological dose from film badge or dosimeter readings.

TABLE I–C

	A Film badge reading	B Biological factor	C Film badge or dosimeter correction	D Effective biological dose factor (column B×C)	E Effective biological dose (column A×D)
From time of fallout until time of evacuation	----------	1/1	3/4	3/4	----------
From time of return to 15 days after initial fallout	----------	3/4	3/4	[1] 1/2	----------
From 15 days until 1 year after initial fallout	----------	2/3	3/4	1/2	----------
Total	----------	----------	----------	----------	----------

[1] The value of 9/16 has been rounded off to 1/2.

Discussion of the biological factor.—As longer periods of time are involved in the delivery of a given radiation dose, lesser biological effects may be expected. From the time of fallout until the time of evacuation probably will be a matter of hours, which has been considered essentially an instantaneous dose, that is, the biological dose factor is 1/1. From the time evacuation could be accomplished to time of return probably would be a matter of several days, so the biological factor has been estimated at 3/4. From 15 days after fallout until 1 year later is essentially a duration of 1 year, so the biological factor has been estimated at 2/3. It will be noted there is no calculation after 1 year, because it is expected under actual conditions of radiological decay and weathering that probably no significant dose will be delivered after a year's time in populated areas around the Nevada test site.

It is recognized that the precise quantities suggested for the biological factor cannot be supported by conclusive evidence. It is reasonable to expect that the delivery of a given radiation dose over a period of many days will have less

biological effectiveness than an instantaneous one (neglecting genetic effects) and that the extension of the period to essentially 1 year should yield a still lower biological factor. One piece of supportive evidence is the work of Strandgvist,[1] where X-ray doses to the skin were factionated into daily amounts, and the biological effects compared to a one-treatment dose. A log-log plot of total doses versus days after initial treatment yielded straight lines. For example, the curve for skin necrosis indicated a ratio of 3,000/6,700 roentgens for a 1-treatment versus 15 daily equally fractionated doses. Of course, daily radiation doses received from fallout are not equally fractionated, so that the ratio would be in the direction of unity. Day-by-day doses delivered from fallout from the 15th day to 1 year are more nearly equivalent than at early times (ignoring the weathering factor). Strandgvist data do not extend beyond 40 days and it is questionable to extrapolate his data in an attempt to derive a similar ratio as above based on 1 year, since other uncertainties are so great, that is, effects of weathering as affecting the rate of dose delivery, and so forth. The ratio would presumably be farther from unity than for a 15-day period. The skin is a relatively rapidly repaired organ and thus may tend to overemphasize the effects of fractionation when considering whole-body gamma doses.[2]

Cronkite reports:[3]

"In the dog, with cobalt gamma rays, the dose that will kill 50 percent of the dogs in a 30-day period when delivered in a single dose at roughly 15 roentgens per minute is approximately 275 roentgens. After this dose of radiation the animals become ill within a period of 7 to 10 days and deaths occur between the 8th and 25th day. Hemorrhage, infections, and profound anemia are prevalent. If the dose is decreased to 100 roentgens per day given over a 14-hour period, the lethal dose is increased to 600 to 800 roentgens. Under both conditions, the animals die in approximately the same period of time with identical manifestations. If the exposure is dropped to 25 roentgens per day given over a 14-hour period, the lethal dose is then increased to well over 1,200 roentgen, and the symptoms and findings are changed."

One problem in such experiments is the evaluation of possibility that the animals may be virtually dead while the exposures are continued. This might be illustrated in experiments using the burro where the daily doses of 400, 200, and 100 roentgens given to 3 separate groups required 3,600 to 4,000, 2,800 to 3,200, and 2,000 to 2,600 total roentgens, respectively, for 100 percent lethality.[4]

Experimental data reported by Boche[5] are summarized below.

Number of days	Dose per day (roentgens)	Dose per week (roentgens)	Survival time (weeks)	Total dose (roentgens)
20	10	60	24	1,440
10	6	36	83	2,988

NOTE.—Unfortunately normal survival times were not given nor were the ages of the animals (dogs).

Blair[6] has taken the two points from Boche's data, inserted these into his (Blair's) equation relating reparable and irreparable damage. The ratio of instantaneous dose to 15-day dose is 350/450 or 0.78, and for 4 months' dose about 350/525 or 0.67.

Blair suggests that "the points are too few to determine the constants (of the equation) with any accuracy but should at least be in the proper range." However, the constants of his equation have checked well with more extensive data on other animals. His equations indicate that the rate of recovery of reparable injury is fastest in the mouse (of the types of mammals selected), about one-half as fast in the rat, and about one-seventh as fast in the guinea

[1] Sievert, Rolf M. The Tolerance Dose and the Prevention of Injuries caused by Ionizing Radiations. British Journal of Radiology, vol. XX, No. 236, August 1947.

[2] See addendum.

[3] Medical Aspects of Radiological Defense. Cronkite, E. P. Lecture to Federal Civil Defense Administration, Regional Conference of Northeastern States of Radiological and Chemical Defense, New York City, October 22, 1953.

[4] UCLA-295. Response of the Burro to 100 Roentgens Fractional Whole-Body Gamma Ray Radiation. Haley, T. J., et al. June 10, 1954. Unclassified.

[5] MDDC-204. Observations on Populations of Animals Exposed to Chronic Roentgen Irradiation. Boche, R. D., 1947. Unclassified.

[6] UR-207. A Formulation of the Injury, Life Span, Dose Relations For Ionizing Radiations. II. Applications to the Guinea Pig, Rat, and Dog. Blair, H. A. July 3, 1952. Unclassified.

pig and dog, but as Blair pointed out, the reaction of the dog is more representative of the larger, longer lived animals.

Discussion of the attenuation and weathering factor.—From the time of fallout until the time of evacuation it is expected that personnel will be kept indoors. (See criteria II.) Major losses due to weathering cannot be relied upon during this period, so that the estimated factor is 1/2. From the time evacuation could have been accomplished until the time of estimated return it is assumed that personnel will be indoors aboout half of each 24 hours and that major losses due to weathering cannot be relied upon. The overall factor is thus 3/4.

The same reasoning applies to the third period of time, i. e., from assumed time of return to 15 days after fallout.

From 15 days after fallout until 1 year later it is estimated that the attenuation due to buildings and the effects of weathering will yield an overall factor of 1/2.

Dose-rate readings have been taken with survey meters outside and inside of houses around the Nevada test site after fallout occurred. The ratio of readings varied with the type of construction of the house and with the location within the building. Generally, the ratio of readings outside to inside a frame house was about 2/1 with a somewhat greater difference for masonry construction. A limited number of film badges were placed outside and inside of some houses during Tumbler-Snapper and also Upshot-Knothole. Ir the first case, the difference in total doses was again 2 to 1 or greater, but during Upshot-Knothole only about a 20 percent difference was noted. In fact, in one case during Upshot-Knothole the film badge inside read higher than outside. The differences between these experimental data will have to be investigated during future operations.

The very nature of the weathering factor makes this a difficult paremeter to evaluate. The probability of occurrence of precipitation and/or winds and to what degree has to be estimated, as well as their effects on radiation levels. Leaching effects were studied on soils about 130 miles from ground zero where fallout had occurred during Upshot-Knothole. Dose-rate readings were insignificantly lower than those predicted by radiological decay according to $t^{-1.2}$ after a period of more than 1 year. One example of the effects of winds was observed during Upshot-Knothole. The fallout from the March 17, 1953, detonation was in a long narrow pattern to the east of ground zero. The second day after a fallout a rather strong surface wind blew almost at right angles across the area, for about a period of a day. Dose-rate readings were taken on the first and fourth days at the same locations and then were compared. The fourth day dose rates were less, by factors of 3 to 6, than those to be expected from the first day's readings, based on rate of decay of $t^{-1.2}$. (Other fallout measurements indicated that the rate of decay of this fallout material was not significantly different from $t^{-1.2}$.) Because of the physical conditions described above, these reductions in contamination probably are near the upper limit to be expected from wind.

Operational feasibility of criteria

It is not the intent here to discuss operational procedures, but it should be indicated that the computing of radiation doses as recommended in criteria I is a not too difficult task. If one assumes a $t^{-1.2}$ rate of decay as a first approximation, then a single graph of dose rates versus times after detonation can be constructed that will represent a 30 roentgen effective biological dose for 1 year. An additional family of curves can be made that will provide the answers to the parameters of how much time would be available before evacuation and of how long a time personnel would have to remain out of the radiation area in order to provide for a savings of at least 15 roentgens.

The highest whole-body gamma dose recorded for any locality where personnel were present outside the Nevada test site was at Riverside Cabins, Nevada (about 15 people), following shot No. 7 of Upshot-Knothole. The maximum theoretical infinity gamma dose was estimated to be 12 to 15 roentgens.

CRITERIA II. PERSONNEL REMAINING INDOORS

When the gamma dose-rate reading as measured by a survey meter held 3 feet above the ground reaches the values given in graph II at the times indicated, it is recommended that personnel shall be requested to remain indoors with windows

and doors closed. Release from this restrictive action should be made on the basis of further evaluation of the radiological conditions.

In the event that there be convincing evidence that the radiation levels given in the graph will be reached, it is recommended that personnel be requested to remain indoors before fallout occurs or before the radiation levels equal those in graph II. Release from this restrictive action should be made on the basis of further evaluation of the radiological conditions.

It is recommended that people who had been out-of-doors during fallout of the above magnitude or greater be advised to change clothing and to bathe. The clothing may be cleaned by normal means. While bathing, special attention should be paid to the hair and any exposed parts of the body.

In the event that the monitoring takes place after the fallout has occurred, and extrapolation of the dose-rate readings equals or exceeds those in graph II at the estimated time of fallout, then it is recommended that the same advice be given as in the preceding paragraph.

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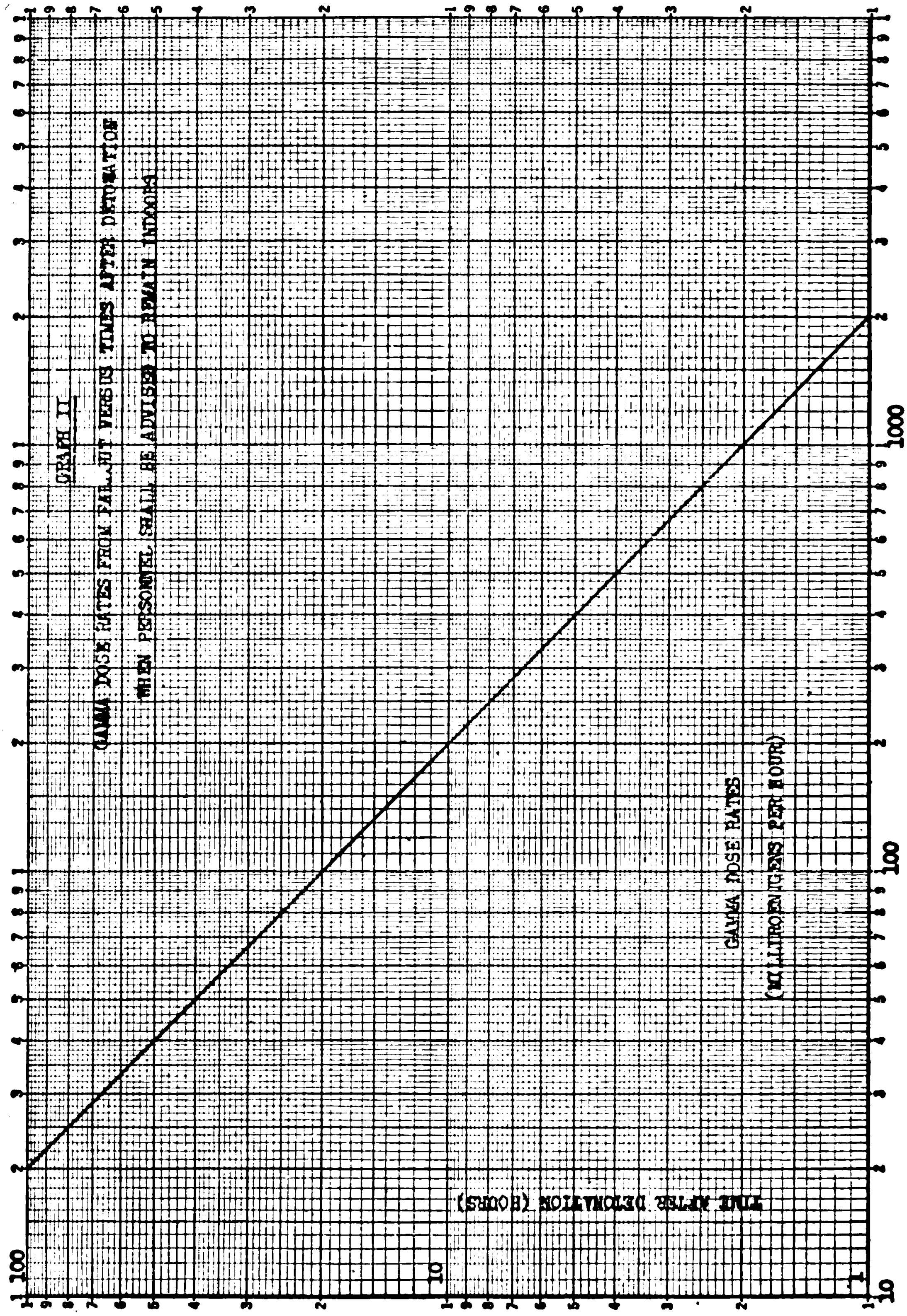
GRAPH II
GAMMA DOSE RATES FROM FALLOUT VERSUS TIMES AFTER DETONATION
WHEN PERSONNEL SHALL BE ADVISED TO REMAIN INDOORS
GAMMA DOSE RATES
(MILLIROENTGENS PER HOUR)
TIME AFTER DETONATION (HOURS)
1
10
100
1000

Discussion

The action of requesting personnel to remain indoors is predicated on the principle that the radiation levels are below those established for evacuation and that this action could reduce the amount of contamination of personnel and reduce somewhat the whole-body gamma dose. (See appendix A for estimates of reduction in whole-body gamma dose.) The actual "savings" healthwise have to be balanced against possible adverse public reaction.

The principal gain in requesting personnel to remain indoors is to prevent or reduce the amount of atomic debris that may actually fall on the body or clothing. Since the peak of fallout usually occurs shortly after the start of fallout, it is important that prompt decisions and actions be taken. Thus, by necessity, the most practical criteria upon which to base a decision are gamma dose rate readings, which are in turn related to the amount of fallout.

Beta dose to skin.—The most immediate solution might be to establish lower permitted dose rate levels at later times after detonation. However, if a series of dose rates are established for increasing times after detonation so that their relationship follows $t^{-1.2}$, then the doses delivered in X hours (before the material is washed off) will be greater for earlier times after detonation. If one were sure of the time that the fallout material was to remain in place, then a scale of dose rates versus time after detonation could be made to yield the same total dose over the X hours. Since there is obviously no set time period for duration of contact that would be valid for all cases, one might assume the worst case where the material remains in place until its activity has decayed to an insignificant level. Dose rates could then be approximated, to yield a given infinity dose, by:

$$D=5At \quad \text{where: } D=\text{infinity dose; } A=\text{dose rate at time "t".}$$

If the above discussion is accepted, then the remaining question is to set the infinity dose. Here, we must be clear that whereas the measurements taken by the monitors, and the data upon which action will be decided will be gamma dose-rate readings, the point of principal concern is the beta dose delivered to the basal layer of the epidermis (assumed as 7 milligrams per square centimeter). The ratio of emission of beta to gamma is a function of time after detonation and follows no simple relationship. Further, this ratio at any given time after detonation has not been firmly established. One report suggests the following data:

Time after detonation:	*Beta/gamma*
72 hours	157/1
168 hours	156/1

These data were obtained from a cloud sample rather than actual fallout material, and were a measure of surface dose on a plaque using a "dosimeter type beta-ray surface ionization chamber."

The method of collection suggests the possibility that the thickness of material on the plaques may be less than that to be expected from the amount of fallout that would be of concern when estimating probabilities of beta burns. This would result in a different angular distribution of the betas influencing the beta dose rate in the direction of a higher value for the plaques.

Another report indicates a beta to gamma ratio of 130 to 1 based on theoretical computations. A third report suggests a radically lower ratio; however, there may be some doubt as to its conclusions since the ionization chamber, used to measure gammas only, had a wall thickness of 1 mm. of bakelite which "* * * excluded a small part of the total gamma dose present, as well as a large, but unknown, fraction of the beta." (The range of 0.35 Mev. betas is about 100 $mg./cm.^2$ or approximately 1 mm. of bakelite.) For our discussion here, we will assume a *surface* beta to gamma ratio of 150 to 1.

In estimating the beta dose to the basal layer of the epidermis, one may refer to the work of Henriques.[7] He exposed the skin of Chester White pigs to plaques containing different radioisotopes. Pertinent data are abstracted as follows:

Isotope	Energy	Surface dose required to produce recognizable trans-epidermal injury (roentgen-equivalent-beta)	Estimated amount of radiation that penetrated skin to a depth of 0.09 mm. (roentgen-equivalent-beta)
Yttrium 91	1.53	1,500	1,200
Strontium 90	.61	1,500	1,400
Ytrrium 90	2.20		

The average maximum energy of the beta particles from fallout material varies with time but will be assumed to be roughly comparable, in respect to depth dose, to yttrium 91 or Sr-90—Y-90. Since the gamma dose at a depth of 7 mg./cm.^{2} would not be significantly different from the surface gamma dose, the ratio of 130 to 1 for beta-gamma will be assumed at the basal layer of the epidermis.

(One experiment with sheep, using Sr-90—Y-90 plaques, showed that 2,500 reps at the plaques' surface produced ulceration in 1 but not another of 2 sheep.[8] On the other hand, 1,000 rads delivered to tissue depth of 7 mg./cm.^{2} from a P^{32} 1-inch diameter disk (type of animal not stated) produced tanning, prolonged erythema, and desquamation.)

It is to be remembered that the above discussion was first based on *surface* gamma dose rates whereas the monitors will be making their gamma measurements at a height of 3 feet. Past field experience has indicated that the gamma reading from ionization-type survey meters at ground level is about 50 percent higher than at 3 feet. Therefore, if it be assumed that a ground level gamma reading of a survey meter is equivalent to a surface dose rate, the ratio of beta dose rate at 7 mg./cm.^{2} to gamma dose rate at *3 feet* is about 200 to 1.

Another approach to estimating the ratio of beta dose rate at 7 mg./cm.^{2} to gamma dose rate at 3 feet is as follows: Assuming a uniform distribution of 1.0 megacurie per square mile of gamma activity, the dose rate reading from an infinite field is about 4.1 roentgens per hour.[9] Calculations given in appendix B indicate that a like concentration of fallout material will produce about 430 reps per hour at 7 mg./cm.^{2} This suggests a beta to gamma ratio of about 100 to 1 which is about a factor of 2 lower than the first approach. Added support to this latter method of estimating beta doses is found in appendix C.

Such considerations may be fraught with pitfalls. For example, the above discussion implies a uniform distribution of fallout material. Obviously this is not correct, but how far this deviates from the facts and to what extent this influences the results is difficult to assess. Calculations indicate that the production of recognizable beta burns from a single particle requires a high specific activity. (See criteria III for discussion.) It may well be, however, that the particles of fallout are close enough to have overlapping of radiation fields and thus require significantly lower specific activity of the particles to produce beta burns. This hypothesis has support in that even the most superficial beta burns of the natives exposed to fallout following the March 1, 1954, detonation showed a general area affected rather than small individual spots. On the other hand, the cattle and horses exposed near the Nevada test site showed burns over areas only about the size of a quarter. Even though these may not have been produced by single particles, they do represent less of an area effect than suggested for the natives. Also, radioautographs of the fallout in areas outside the Nevada test site suggest the occurrence of individual particles with nonoverlapping of radiation fields. However, in nearby areas where the fallout was relatively heavy, there was a definite overlapping of the fields.

[7] Effect of Beta Rays on the Skin as a Function of the Energy, Intensity, and Duration of Radiation. Henriques, F. W. Laboratory Investigation. Vol. 1, No. 2. Summer 1952.
[8] Comparative Study of Experimentally Produced Beta Lesions and Skin Lesions in Utah Range Sheep. Lushbaugh, C. E., Spalding, J. F., and Hale, D. B. LASL, November 30, 1953. (Unclassified.)
[9] Effects of Atomic Weapons. 1950.

With our present knowledge it should be stated that due to the particulate nature of fallout it would not be possible to establish reasonable and operationally workable criteria that at the same time would guarantee that there *never* would be an occurrence of a beta burn.

If one were to accept the assumed beta to gamma dose rates of about 100–200 to 1 (measured under the conditions given above), this might mean an infinity beta dose of 1,000 to 2,000 reps to the basal layer of the epidermis when the whole body infinity gamma dose was 10 roentgens. Of course, the fallout material may be removed before the infinity dose is delivered; yet, on the other hand, it is not improbable that it could remain in the hair for essentially this length of time. In the case of a 1-hour fallout, almost one-half of the dose would be delivered in the next 24 hours.

The efficiency of a surface for collecting and holding the fallout material is important. It is not surprising that the highest dose rate readings as well as biological effects were noted on the hair of the natives and also on parts of the exposed body where perspiration was present. Further, it was observed that even one layer of light cotton material was sufficient to protect against beta skin damage in most cases.[10] This was due probably not to the relatively small attenuation of the betas by the clothing but rather to the physical situation of holding the radioactive material at some distance from the skin, which effect would be relatively large.

An added consideration is the possibility of high beta doses delivered to personnel from the fallout material lying on the ground and other surfaces. If the highest degree of contamination considered under this policy is safe when in direct contact with the skin, then the beta dose from an equally contaminated ground will not be hazardous. (See criteria III for discussion on unequal contamination on personnel.) However, it is true that the contamination may exceed the amount to deliver dose rates given in graph II and yet not be great enough to consider evacuation. Some personnel may not go indoors, and those who did will eventually be released from this restrictive action and then may walk around in a relatively highly contaminated area. Because of the more limited range of the beta, the location of greatest concern is the lower legs.

One report estimates a beta to gamma dose rate ratio of about 75 to 1 at 10 centimeters above the ground.[11] Under criteria I it was recommended that consideration be given to evacuation when the gamma dose rate reading at 3 feet was, for example, about 6.2 roentgens per hour at H+3 hours. Roughly, this would correspond to about 575 reps per hour of beta at 10 centimeters. Of course, this activity decays, and also it is presumed that personnel would be sent indoors, at least for a few hours. On the other hand, it strongly suggests that biologically significant doses may be delivered to the feet if not protected. Skin lesions were frequent on the bare feet of the natives evacuated during Castle. This probably was a combination of beta dose from material on the ground and from that scuffed up over the bare feet and then clinging to the skin. (No lesions were observed on the bottom of the feet, undoubtedly due to the thick epidermis.) It would be expected that normal closed-type footwear (as compared to open sandals) would afford adequate protection to the feet from such high beta doses as discussed here. There is still no guaranty that beta radiation from material on the ground will not deliver significant biological doses to the ankles and perhaps lower legs, after personnel are released from staying indoors. For example, if the beta dose at 10 centimeters above the ground is 575 reps per hour at H+3 hours, it would be about 250 reps per hour 3 hours later and 160 reps per hour 6 hours later.

One further possibility is the accumulation of radioactive material around the ankles and lower legs resulting from normal walking about the area. This is discussed under criteria III.

Data on human exposures.—The work of Henriques[12] suggests that at the depth of 0.09 mm. in living porchine skin (maximum thickness of epidermis) that "1,400±300 roentgen-equivalent-beta" (delivered over short periods of time so that they may be assumed to be instantaneous) is required to produce recognizable transepidermal injury. The curve of biological damage rises rather

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[10] ITR–923. Study of Response of Human Beings Accidentally Exposed to Significant Fallout Radiation, Cronkite, E. P., et al. May 1954.

[11] AD–95 (H). An Estimate of the Relative Hazard of Beta and Gamma Radiation from Fission Products. Condit, R. I., Dyson, J. P., and Lumb, W. A. S. NRDL 1949. (Unclassified.)

[12] Op. cit.

sharply so that at a dose of just under 2,000 reps (at 0.09 mm.), the epidermis may be expected to exfoliate and in the majority of cases go on to develop chronic radiation dermatitis persisting for months.

The preceding discussion suggests that, using the gamma dose rates listed in these criteria, which are based on an estimated 10 roentgen infinity gamma does, as high as 2,000 reps might be delivered to the basal layer of the epidermis over a period of time covered by the lifetime of the radioactive material.

There have been instances where the calculated infinity gamma dose in areas where personnel were present around the Nevada test site have reached 12 to 15 roentgens, but there have been no known cases of beta burns in these areas. The number of persons involved in these areas of highest contamination was relatively small, perhaps a few dozen, and with an observed duration of fallout of about 1 hour it is possible that they were not in a position to receive the full fallout. Likewise, minute areas of the skin may have been so affected yet not detected or reported. In other areas encompassing some 2,000 people the infinity gamma dose was about 8 roentgens and no instances of beta injury appeared.

The estimated whole-body gamma dose to natives evacuated from the island of Utirik following the March 1, 1954, detonation at the Pacific Proving Ground was about 15 roentgens for a period of about 3 days, but no beta burns appeared. It is fair to assume here that direct contamination took place due to their mode of living, including housing that was quite open to air currents. Gamma dose rate readings were taken over the bodies of the natives at about H+78 hours both on the beach and after boarding the ship. On the beach the personnel readings averaged about 20 mr. per hour gamma (but this probably included some contribution from the ground contamination), and after wading through the surf and boarding the ship the levels averaged 7 mr. per hour gamma.

The 18 natives on Sifo Island, Ailinginae Atoll, received an estimated whole-body gamma dose of 75 roentgens in about 2¼ days. Of these, 14 later experienced slight beta burns, 2, moderate burns, and none showed epilation.

In the case of the Rongelap natives, the estimated whole-body dose was about 170 roentgens in about 2 days. All 64 natives later experienced beta burns to some degree from slight to severe, and over half of the natives showed epilation from slight to severe.

The 16 natives from Rongelap evacuated directly by air to Kwajalein had personnel gamma dose-rate levels generally 80 to 100 mr. per hour although 1 was as high as 240 mr. per hour and 1 as low as 10 mr. per hour (at H+ about 55 hours). The remaining 48 natives evacuated by ship were reported to have personnel readings that "averaged" 60 mr. per hour before decontamination. The picture is further confused because some of the natives had bathed and some had not before the arrival of the evacuation team.

Most of the 28 United States service personnel stationed on Eniwetok Island, Rongerik Atoll, received about 40 to 50 roentgens, based on film badge readings. Three members of the group who were located for part of the time in another section of the island were estimated to have received somewhat higher doses. Seventeen of the twenty-eight personnel showed only slight, superficial lesions with one questionable case of epilation. It should be pointed out that the personnel were in metal buildings during some of the fallout time and for most of the time thereafter until evacuation. This reduced the direct contamination as well as the whole-body gamma dose. A film badge hanging on the center pole of a tent at one end of the island read 98 roentgens. Calculations based on dose-rate readings at another part of the island indicated somewhat lower doses, if personnel had remained in the open for the period of time from fallout (about H+7.5 hours) to evacuation (at about H+34 hours). Upon arrival at Kwajalein 1 personnel gamma dose rate reading was as high as 250 mr. per hour at about H+35 hours.

The above data do suggest that there may be possible a rough bracketing of gamma-beta doses versus beta burns. On the one hand, the natives from Utirik received an estimated whole-body gamma dose of 15 roentgens and showed no evidence of beta burns. On the other hand, the natives on Sifo Island, Ailinginae Atoll, received about an estimated whole-body gamma dose of 75 roentgens, with 14 personnel showing slight burns, 2, moderate burns, 2, no burns, 3 with moderate epilation, and 15 with no epilation. In addiiton, Rongelap natives received 170 roentgens whole-body gamma dose, and about 90 percent showed some degree of lesions and 56 percent some degree of epilation.

It is to be recalled that: (*a*) The natives probably were out of doors and received the full fallout; (*b*) the oily hair, seminaked, perspiring bodies, including bare feet, and lack of bathing for most, would tend to collect and hold the fallout material; (*c*) the time of delivery of essentially all of the doses was 2 to 3 days. Further, it may be speculated that the fallout on the more distant island of Utirik (about 300 statute miles) would consist of smaller particles and also perhaps lesser possibility of overlapping of radiation fields from these particles.

Some of the relevant data are summarized in table II. Due to the uncertainty of the degree of exposure of personnel on Rongerik to the direct fallout, this group is not included. It is to be immediately emphasized that any comparisons made or implied in the table are at the most only semiquantitative. Table II will be referred to in criteria III and IV but is included here as a summary of the data discussed above.

TABLE II

I	II	III	IV	V	VI			
Location	Estimated time of fallout (hours)	Best estimate of whole-body gamma dose (roentgens)	Skin effects	Personnel reading	Best estimate of average dose rates (mr./hr.) of the islands (taken at 3 feet above the ground) and of natives (personnel readings) after removal from radiation field, both at approximately same time			
					Island	Personnel	Ratio	Approximate time
Rongelap	5½	170	Lesions: 6 none. 19 slight. 22 moderate. 17 severe. Epilation: 28 none. 11 slight. 11 moderate. 14 severe.	(a) Majority: 80–100 mr./hr. at H+54 hours.[1] (b) Average: 60 mr./hr. at H+50 hours. Corrected average: 80 mr./hr.[3]	1300	80	16/1	H+50 hours.
Ailinginae	5½	75	Lesions: 2 none. 14 slight (very superficial). Epilation: 15 none. 3 moderate.	Average: 40 mr./hr. at H+52 hours. Corrected average: 53 mr./hr.[3]	410	53	8/1	H+52 hours.
Utirik	16–18	15	Lesions: None. Epilation: None.	Average: 20 mr./hr. Assumed: 15 mr./hr. at H+78.[4]	110	15	7/1	H+78 hours.

[1] 16 natives evacuated by air to Kwajalein and monitored upon arrival.

[2] 48 natives evacuated by U. S. S. *Philip* and monitored aboard the ship. Data suggest meter readings low by about 50 percent since natives from same island read 80 to 100 mr./hr. at Kwajalein some 4 hours later with calibrated meters.

[3] 40 mr./hr. corrected to 60 mr./hr. according to information in footnote 2. Report did not indicate range of values among individuals nor at different parts of body.

[4] Readings taken by monitors from the *Renshaw* on the Utirik beach where there may have been some contribution to dose rates from land. After wading to ship, average personnel readings were 7 mr./hr.

Data on animal exposures.—The data on animal exposures are less firm than those for humans. Unmistakable beta burns occurred on cattle at Alamogordo in July 1945, on cattle at the Nevada Proving Grounds in spring 1952, and on horses in spring 1953. (The skin damage observed on sheep in the spring 1953 was not established to be beta burns.) However, the exact positions of the animals in relation to known amounts of fallout are not clear.

Following the last detonation of the spring 1952 series at the Nevada Proving Grounds, about one-half of a herd of 150 head of cattle were found to have evidence of beta burns. They were thought to have been 15 to 20 miles from ground zero in Kawich Valley to the northeast and to have been exposed to fallout from the last detonation. Highest dose rate readings taken along a dirt road running lengthwise through this valley integrated to 75 to 100 infinity gamma doses.

During Upshot-Knothole, 16 horses showed skin lesions over the back, and eye damage was noted in a few. The best evidence indicated that the horses were some 10 to 12 miles to the east of ground zero on March 17, 1954, where the fallout occurred from the first detonation (about 15 KT on a 300-foot tower). Radiation levels in this area are not known with certainty, but the fallout occurred in a narrow band and was carried by relatively high velocity winds so that it probably fell on the horses at a time less than 1 hour. If so, probably more than one-half of the infinity dose was delivered during the next day.

Addendum

Since the original discussion above was written, further consideration has been given to the work of Strandgvist and others [13] on the effect of fractionation of doses delivered to the skin and the onset of the observed results. It will be recalled (p. 10) that X-ray doses to the skin were fractionated in equal daily amounts, and the biological effects compared to a one-treatment dose. A log-log plot of total doses versus days after initial treatment yields straight lines.

Basically, this means that as doses are being delivered to the skin a certain rate of repair is taking place. The overall effect might be that higher initial doses from fallout material might be allowed than if one were to integrate the dose over a period of time without consideration for the repair. Because of the difference in shapes of the total beta dose curves for varying times of initial fallout versus Strandgvist X-ray curves the difference between the two curves cannot be expressed as a simple relationship.

Strandgvist quotes a 1,000 roentgen dose in 1 treatment to produce erythema using X-rays (a somewhat smaller number than other data quoted above), 1,250 roentgens if divided into 2 equal daily doses, 1,450 roentgens if divided into 3 equal daily doses, etc. Of course, there are differences between these X-ray doses and beta doses from fallout material, such as differences in doses at increasing depth of tissue and the fact that the X-rays were delivered essentially as an instantaneous dose at intervals of a day while the beta dose rates are assumed to follow the $t^{-1.2}$. However, accepting the assumptions of biological equivalence of these roentgen and beta doses and $t^{-1.2}$, one may then ask the question, "What will the beta dose rates at varying times after detonation that the contamination occurs such that the integrated doses to the skin will at no time equal Strandgvist curve for erythema?"

For early fallout times the limiting factor will be to keep the first day's beta dose below 1,250 reps; for later times of initial fallout the first day dose may be less than 1,250 reps but subsequent accumulative doses may be greater than Strandgvist curve. A family of curves was prepared of beta dose rates versus time after contamination such that each would meet but not exceed Strandgvist curve for erythema for times out to 40 days, then, based on the discussion contained under Criteria I, a conversion factor of 125 was selected to convert beta dose rates at a depth of 7 mg./cm.^{2} of tissue to gamma dose rates at 3 feet above an infinite plane. These gamma dose rates are plotted in appendix C (a).

If one accepts all the assumptions that go into preparing this curve, then one does not have to estimate the variable of how long the fallout material was in contact with the skin, for the curve suggests that as long as the initial indicated gamma dose rates are not reached, then erythema might not be expected to appear. (However, this approach still does not give assurance that *single* hot particles will not produce erythema.)

Generally, the gamma dose rate readings in the curve (appendix C (a)) suggest theoretical maximum infinite gamma doses of about 20 roentgens for a 1-hour fallout, to about 55 roentgens for a 2-day fallout. For those early times after detonation when relatively heavier fallout might be anticipated, this in-

[13] Sievert, Rolf M. The Tolerance Dose and the Prevention of Injuries Caused by Ionizing Radiations. British Journal of Radiology. Vol. XX, No. 236, August 1947.

finity gamma dose is 2 to 3 times greater than the 10 roentgens which was used as a basis of developing criteria II. However, there are two further considerations: One, the interpretation of the data, and certainly the assumptions made in developing the curve in appendix C (a) are open to discussion. Two, if one accepts the interpretations and assumptions it means a safety factor of 2 to 3—not an unreasonable quantity.

Operational feasibility.—Under the criteria recommended in criteria II, there would have been two occasions in the past where personnel would have been requested to remain indoors. Once was at Lincoln mine following the second detonation of Upshot-Knothole where they were so requested to remain indoors for 2 hours and the other occasion would have been at Riverside Cabins (population about 15) following the ninth detonation of the same series. The dose rate reading at Lincoln mine was 580 mr. per hour at H+2. In the case of Riverside Cabins, however, the radiological conditions were not ascertained until after the fallout had occurred. The maximum infinity gamma dose in the latter case was 12 to 15 roentgens.

Personnel were requested to remain indoors (for about 2 hours) following the ninth detonation of Upshot-Knothole. The highest dose rate reading was 320 mr. per hour at H+4.5 hours. This is less than the current recommendations.

CRITERIA III. DECONTAMINATION OF PERSONNEL

Where it is not possible to monitor personnel outside of a general radiation field, it is recommended that an estimate be made of the degree of personnel contamination by determining the location of the individual at the time of fallout. In the event there is uncertainty as to the validity of such an estimate, the assumption will be made that the individual was out-of-doors. In those areas where the infinity gamma dose equals or exceeds 10 roentgens, it is recommended that the individual be advised to bathe and to change clothing.

For personnel being monitored outside the general radiation field where personnel contamination exists over relatively large areas of the exposed body (one-half square foot or more):

> When the reading of a survey instrument held with the center of the probe or center of the ionization chamber 4 inches from the center of the contaminated area equals or exceeds the values given in graph III, it is recommended that personnel shall be advised to bathe and to change clothing.

For personnel being monitored outside the general radiation field, where personnel contamination exists over relatively small areas of the exposed body (less than one-half a square foot):

> The recommended maximum values shall be one-half those given in graph III. Monitoring of the head, arms, hands, lower legs, and feet will be considered as coming under this category. Washing may be limited only to the contaminated parts, and also a change of clothing may not be indicated unless the radiation levels exceeds those stated below concerning monitoring of exterior surfaces of clothing.

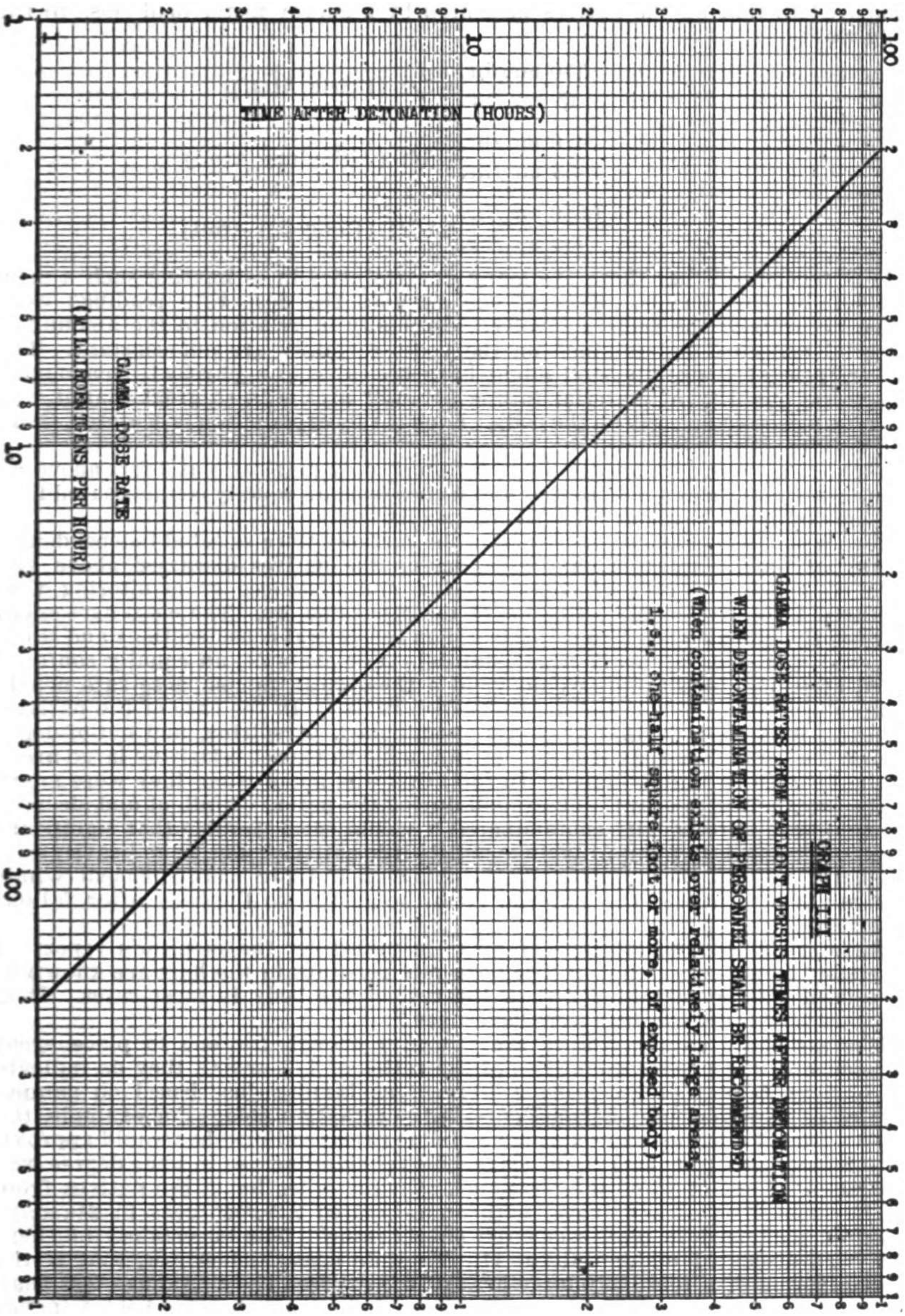
For personnel being monitored outside the general radiation field, and the contamination exists over only spots of exposed body (about the size of a half dollar or less):

> The recommended maximum values shall be one-fifth those given in graph III. Washing may be limited only to the contaminated parts, and also a change of clothing may not be indicated unless the radiation levels exceed those stated below concerning monitoring of exterior surfaces of clothing.

For personnel being monitored outside the general radiation field and the contamination exists over any size area on the exterior surface only of the clothing:

> The recommended values under these conditions will be twice those given in graph III. The first recommended action shall be to resort to such simple acts as brushing off the clothing. If this action does not reduce the radiation levels to twice those given in graph III or less, then personnel shall be advised to change clothing and to bathe.

When the general contamination of a community of the degree to produce an estimated maximum theoretical infinity gamma dose of 20 roentgens or greater, personnel who have been out-of-doors at any time during the first 2 days and generally moving around in the area (as opposed to such an act as walking only between a building and a vehicle) shall be advised to brush off the footwear (outdoors), to bathe, and to change clothing as soon as possible after the final return indoors each day. In addition, personnel who go out-of-doors for any length of time during the first 2 days after such a fallout shall be advised to wash their hands at least after the final return indoors each day, and more frequently if possible.


GRAPH III
GAMMA DOSE RATES FROM FALLOUT VERSUS TIMES AFTER DETONATION
WHEN DECONTAMINATION OF PERSONNEL SHALL BE RECOMMENDED
(When contamination exists over relatively large areas,
i.e., one-half square foot or more, of exposed body)
TIME AFTER DETONATION (HOURS)
GAMMA DOSE RATE
(MILLIROENTGENS PER HOUR)
1
10
100

Discussion

Data on humans.—In table II it was suggested that the relative average gamma dose rates from an infinity contaminated field at 3 feet above the ground compared to that on the natives measured by a survey meter held close to the body was:

$$\frac{110 \text{ mr./hr.}}{15 \text{ mr./hr.}} \cong 7/1 \text{ (Utirik Atoll)}$$

$$\frac{410 \text{ mr./hr.}}{53 \text{ mr./hr.}} \cong 8/1 \text{ (Ailinginae Atoll)}$$

$$\frac{1{,}300 \text{ mr./hr.}}{80 \text{ mr./hr.}} \cong 16/1 \text{ (Rongelap Atoll)}$$

It is recognized that there are many uncertainties in estimating such a relationship by this means. Even if one assumes the dose rate readings were taken accurately, the factors involved, especially in relation to the amount of material collected and retained on the body, certainly are not constant. The higher ratio at Rongelap Atoll might have been due to a physical phenomenon where the quantity of material falling per unit area was so great that it was not retained so completely on the body. Even if this explanation is accepted, there still remain many questions.

Theoretical considerations indicate a gamma dose rate ratio at 3 feet above an infinitely contaminated field to that at 4 inches from an equally contaminated field of 6-inch radius to be about 7/1. (See appendix D.)

The sizes of areas and distances from the surfaces were selected independently of any of the information on the fallout on the natives discussed above and were estimates of areas of contamination and distances of monitoring that appeared to be reasonable estimates of these parameters. The close agreement between the gamma dose rate ratios based on theoretical considerations and those observed with the natives is circumstantial. For example, an equally contaminated area of 3-inch radius would yield a theoretical gamma dose rate nearly 3 times less than the selected area of 6-inch radius. In the case of the natives, however, it is believed that they were seminaked, perspiring, and out-of-doors during the fallout, so that it is not unreasonable to expect relatively large areas of the body to be contaminated. In fact, this was noted when they were monitored. By their acts of walking around during the period of fallout and sleeping on mats that were heavily contaminated it would seem possible that significant areas of the bodies of the Ailinginae and Utirik natives could be as heavily contaminated as was the ground. (It is unknown if there were sufficient winds that might have raised the material from the ground to the body after fallout occurred.)

There is further uncertainty of what is meant by the monitor's report of "average" personnel readings. The dose rate readings in the hair are known to have been significantly higher than the rest of the body in most cases. It is unknown how these readings were "averaged."

Whereas these data certainly are not firm enough for one to place great confidence in the precise quantities of the ratios of 7/1 or 8/1, they do indicate the obvious fallacy of accepting a 10-roentgen infinity dose based on gamma dose rates measured on personnel outside the radiation field. For example, the natives from Ailinginae showed personnel dose rates readings that would approximate 9 roentgens (gamma) in 2¼ days, and yet skin damage to some degree was evident in 14 out of 16 of the personnel. On the other hand, the natives from Utirik showed no skin damage, with an estimated 2.2 roentgens in 2½ days based on gamma dose rates measured on personnel. The uncertainty of these data was discussed under criteria II. They do suggest, however, that if the contamination of a relatively large area of the exposed body produces less than 1 roentgen infinite gamma dose as measured by a survey meter held 4 inches from the surface there is a large probability that beta burns will not result. (See also discussion under criteria II.)

Doses from small sources.—When the same dose rate reading is produced at a given height above a surface from a smaller area, the amount of contamination per unit area is greater (other factors being equal). Therefore, it would seem desirable to reduce the recommended dose rate levels when relatively small areas are involved. It is recognized that radiation from another nearby spot may

contribute to the survey meter reading when monitoring a small area on personnel, but this has not been taken into account, first, because of the difficulty of establishing a prior appraisal of this variable factor and, second, whatever this contribution may be it will now become an added safety factor.

Of course, the problem is still complex, because when considering smaller and smaller areas the eventual end point is a single particle. An estimate of beta doses at the surface of an imaginary sphere surrounding a fallout particle is given in appendix E and an estimate of beta doses from a single particle required to produce recognizable erythema is presented in appendix F. Calculations indicate that the specific activity of some individual particles found in fallout would be great enough to produce recognizable erythema if held in contact with the skin for less than 1 day, yet the gamma dose rate reading at 4 inches may be relatively small. (See appendix G.)

Additional information on doses from individual particles has recently been reported.[14] The particles found in and around Hanford consisted principally of three radioisotopes, Ru-103, Ru-106, and its daughter Rh-106. The data and calculations in appendix H also strongly indicate that a single fallout particle could produce a recognizable erythema.

Contamination of clothing.—In the case of contamination of clothing, higher dose rates might be tolerated than those for exposed parts of the body. This was exemplified in the natives where no beta burns were observed under clothing of the most highly contaminated personnel. (This does not include such areas as under the waist line where material apparently collected and was held in place.) On the other hand, very large increases in contamination should not be tolerated since it is possible for the clothing to be rearranged so as to bring the contaminated surface in contact with the skin. Further, it is not unlikely that one may rub his hands over his clothing and then through the hair where the material could be held in place for relatively long periods of time.

Beta exposure to the hands.—A further consideration is the beta dose to the hands resulting from handling objects contaminated with fallout material. Although some data are available on beta burns from handling radioactive objects, the conditions are so different from those associated with fallout that comparisons probably would not be valid.[15]

If the above assumptions and calculations are correct concerning contamination of a general area from fallout, then the transfer of all the radioactive material to the hands from an object of equal area would not constitute a hazard. Thus, one might consider using as criteria for monitoring objects, the dose readings given above for monitoring personnel outside the general radiation field. However, the problem is more complex, since the hands may come into contact with contaminated surfaces many times larger in area than the hands, with an undetermined percentage of activity being transferred to the hands. Of course, an added uncertainty is the frequency of washing of the hands and/or the rubbing off of the material from the hands.

Further, one might speculate that a given surface could have significantly higher contamination than the general area and that the handling of such a surface could constitute a greater risk. This might be true because of the greater amount of activity transferred to the hands or because of the doses delivered during the time of actually handling the object. The uncertainty of the percentage of transfer of material has been mentioned. One uncertainty in the second case is the length of time the object would be handled.

Based on calculations in appendixes B and D, when an object is held in a hand, a rough estimate of the ratio of dose rates of beta to the basal layer of the epidermis to that of the gamma reading on a survey meter held 4 inches away from an object 2 inches in radious (outside a general radiation field) might be 5,000 to 1 (appendix I). Thus, if this object were contaminated with the same activity per unit area that would produce an infinity 10-roentgen whole-body gamma dose from general contamination of the area, it would produce about 50 mr. per hour gamma at 4 inches away at H+1 hours, and about 250 reps per hour at a depth of 7 mg./cm.^{2}. Since the palms of the hands have an approximate epidermal layer of about 40 mg./cm.^{2} the beta dose to the basal layer would be about 170

[14] HW-33068. A status report. September 15, 1954.

[15] Beta Ray Burns of Human Skin. Knowlton et al., The Journal of the American Medical Association, vol. 141, No. 4. September 24, 1949.

reps per hour. (The time of H+1 was selected to show about the highest magnitude of dose rates.) If one assumes that the decay is according to $t^{-1.2}$, then the total beta dose to the basal layer of the epidermis of the hand in the next 10 hours would be about 320 reps.

Whereas the above estimates do not indicate an alarming situation, a more serious problem may come when the contamination is just less than that where evacuation is indicated. For example, the contamination of the general area may be 5 or 6 times that used as an illustration in the preceding paragraph, without evacuation being recommended. Thus, beta dose rates from handling objects, especially in times soon after fallout, may be high enough to be a problem. A simple and expedient procedure to reduce this factor is frequent washing of the hands after handling objects that were in the fallout.

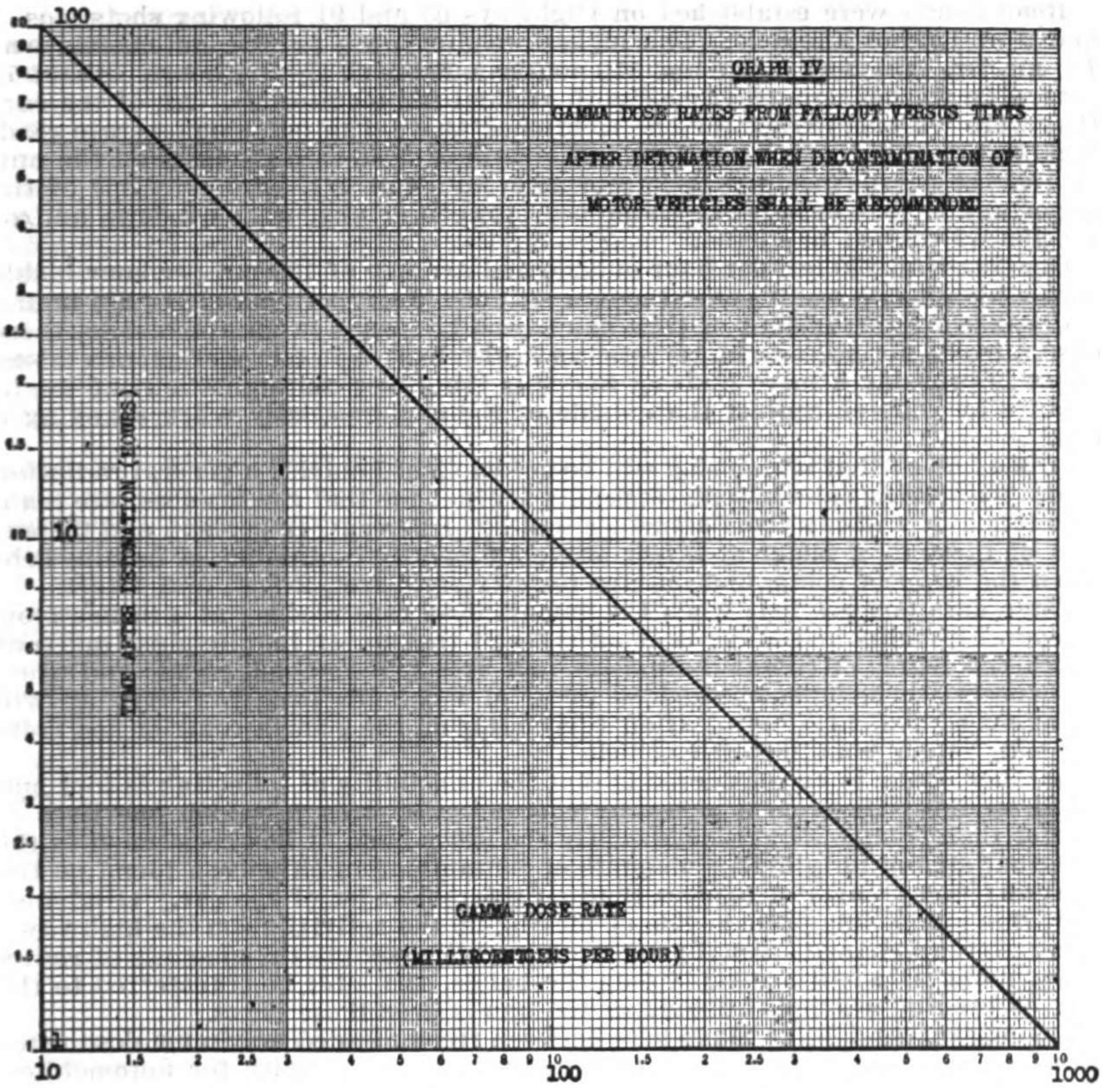
Beta exposure to the feet and lower legs.—It was suggested in criteria II that normal closed-type footwear (as compared to such as open sandals) would probably afford adequate protection against significant beta doses to the feet from fallout material on the ground. There is still the added problem if the material be scuffed up and cling to the ankles and lower legs. If there were no intervening clothing, or perhaps even with thin stockings or socks, this might result in significant biological beta doses being delivered to these parts. For example, if the gamma dose rate reading at H+3 hours were something less than 5 roentgens per hour, evacuation would not be indicated. However, for fallout material of the same concentration in contact with the skin the beta dose rate at 7 mg./cm.^{2} would be about 600 reps per hour. (See appendix B.) Presumably, personnel would be kept indoors for a few hours, but upon release the approximate beta dose rates at 7 mg./cm.^{2} would be 260 reps per hour 3 hours later, or 210 reps per hour 6 hours later. In addition, there is the variable factor of what concentration of fallout material may accumulate in the ankle region by walking around an area.

A concentration of fallout material on the ground that would result in about 20 roentgens maximum theoretical infinity gamma dose if in contact with the skin, would result in a beta dose rate to the basal layer of the skin of about 1/4 those indicated in the previous paragraph.

CRITERIA IV. MONITORING AND DECONTAMINATION OF MOTOR VEHICLES

It is recommended that when the predicted fallout across a main highway will be equivalent to a 10-roentgen infinity gamma dose or higher, vehicles be held until after the actual fallout has essentially ceased. They should be then warned to proceed with windows and air vents closed, and the cars should be monitored after passing through the contaminated area. When 5 to 10 roentgens are predicted across a main highway, vehicles should be warned to proceed with windows and air vents closed and should be monitored after passing through the contaminated area. Monitoring and warnings should be continued until there is reasonable belief that no or very few additional vehicles will exceed the values given in graph IV.

When the dose rate reading taken inside a vehicle, or taken over any exterior area that is readily accessible, equals or exceeds the values given in graph IV, the vehicle shall be cleaned inside and outside. Exterior areas to be monitored should include the wheels and under parts of the fenders but not the under carriage. The survey meter should be held approximately 4 inches from any surface.



Discussion

In the past, fallout has occurred across highways in significant quantities. Table IV–b below indicates some pertinent data during Upshot-Knothole.

TABLE IV–B

Shot No. (chronological)	Approximate yield (KT)	Tower (feet)	Time of fallout (hours)	Estimated dose rate reading of highway at time of fallout (mr./hr.)	Location	Approximate distance from ground zero (miles)
1	----------	300	1¼	920	30 miles south of Alamo on Highway No. 93.	60
1	----------	300	2¾	260	1 mile north of St. George, Utah.	130
6	----------	300	5	325	Junction of U. S. Highway No. 91 and Nevada Highway No. 40.	80
7	----------	300	4½	760	20 miles northwest Glendale, Nev., on Highway No. 93.	65
7	----------	300	7	400	8 miles west of Mesquite, Nev., Highway No. 91.	105
9	----------	300	2	1,000	36 miles north Glendale on Highway No. 93.	60
9	----------	300	3¾	420	St. George, Utah, Highway No. 91.	130

Road blocks were established on Highways 93 and 91 following shots Nos. 7 and 9 of Upshot-Knothole. The highest reading on a private automobile was 100 mr./hr. (gamma) inside and 110 mr./hr. outside at H+3½ hours. About 75 cars were washed (roughly one-eighth of the total monitored). All of the cars that were washed, except the one mentioned above, had outside dose rate readings less than half of the highest. The ratio of dose rate readings on the outside of the car to inside varied from unity to about 4/1. Probably one of the important factors here is the difference between driving with windows and/or ventilators opened or closed.

One bus read 250 mr. per hour outside and average of 100 mr. per hour inside with a high inside reading over the rear seat of 140 mr. per hour at H+8¾ hours.

Considering the amount of time one normally spends in an automobile, these dose rates do not necessarily represent a health hazard in terms of gamma doses. What is probably a more limiting factor is the direct contamination one might acquire by rubbing against the outside of the car, especially when changing a tire.

It is assumed that monitoring will be accomplished outside a general radiation field. Theoretical calculations (appendix D) indicate that gamma dose rate readings taken at 4 inches from a surface will be 51 percent, 42 percent, and 27 percent of those by a meter at 3 feet above an equally contaminated infinite field when the radii of contamination are resjectively 3 feet, 2 feet, and 1 foot.

These data suggest that when the gamma dose rate reading at 4 inches from a generally contaminated car is about one-half that for an infinite plane taken at 3 feet, the degree of contamination per unit area will be about equal; and when the wheels are being monitored ½ to ¼ of a gamma dose rate reading will represent equivalent contamination (depending on the gamma contribution from the body of the contaminated vehicle).

Another factor to be considered is that the probability of collecting fallout material on the body from a generally contaminated area in which one lives is greater than from one's automobile. On the other hand, it has been noted in the past that significantly higher amounts of contamination have been found on the tires and under parts of fenders than on the remainder of the car. (Undoubtedly, this is a simple phenomenon of picking up the activity from the highway.) It one were to change a heavily contaminated tire, significant amounts of radioactive material might accumulate on the hands, and later be transferred to the hair or eyes by a simple rubbing of the hands over those parts.

A comparison might be made here between recommended maximum dose rates found on personnel and the establishing of levels of activity for automobiles. There is one obvious difference, howewver; in the first case the material is already on the person while in the second case one has to introduce the factor of probability of transfer of contamination (and to what degree) from the car to the body.

The dose rates (measured as stated) in graph IV would represent about equal contamination per unit area for a car as for an infinite plane if the car were rather uniformly contaminated. If the activity were confined, say, principally to the tires and under parts of the fenders, the dose rate readings might represent nearly twice the degree of contamination. One must weigh this condition with the probability that a tire will be changed before he activity has decreased significantly.

A given dose rate reading inside a vehicle may represent less contamination per unit area due to the contribution of gamma radiation from the exterior of the vehicle. On the other hand, contamination within a vehicle would more probably be picked up by personnel than if it were on the outside. Further, it is recognized that significantly high concentrations of radioactive fallout may accumulate in such parts as the air filters of an automobile. Again, this has to be weighted against the probability that they will be handled before the activity has decreased to low levels plus the fact that it is relatively difficult to monitor such parts on a mass basis. The uncertainties present in estimating possible hazards from vehicle contamination would not justify fine distinctions in monitoring the various parts. A thorough cleaning, inside and outside, would appear to be the best solution.

One of the obvious ways to avoid much of the problem discussed in criterion IV is to prevent vehicles entering an area during the time of fallout. This will not prevent the first vehicles passing through from picking up activity on the tires from the highway. It is believed, however, this will not constitute such a troublesome problem and past experience has indicated that the activity found

on the tires noticeably decreased after several cars had passed over the highway. Further, if vehicles are not present in the fallout it will help reduce contamination of the passengers and of the insides of the vehicles.

Operational feasibility.—In the past, the criteria used for washing cars has been 7 mr./per hour, and at a later time 20 mr./per hour (gamma), inside a vehicle. This resulted in washing about 75 cars (roughly one-eighth of the total monitored) following the seventh and ninth detonations of Upshot-Knothole. Under the recommendations given in criteria IV, the bus mentioned above, but probably none of the cars, would have been washed.

The data given in graph IV-b indicate that if these radiation levels given had been predicted before the fallout, Highways Nos. 91 and 93 would have been closed prior to the fallout from the seventh detonation and possibly Highway No. 93 for the ninth detonation.

CRITERIA V. CONTAMINATION OF WATER, AIR, AND FOODSTUFFS

In any area where the theoretical gamma infinity dose exceeds 10 roentgens, adequate sampling of the water, air, and foodstuffs should be made to ascertain the conditions of possible contamination. Based on past data, however, it is not expected that under those conditions of fallout, where the radiation levels are below those stipulated for possible evacuation, that the degree of contamination will be a health hazard. (Nor is it implied here that any level above this does constitute a serious contamination of water, air, or foodstuffs.) Therefore, it is recommended that no action be taken in regard to limiting intake except to advise the washing off of such exposed foods as leafy vegetables when that action seems desirable.

Discussion

Water.—Table VI-A lists the six locations having the highest concentrations of fission products in water sources during Upshot-Knothole, and for comparative purposes the estimated external theoretical maximum gamma infinity doses.

TABLE VI-A

Locality	Concentration (microcuries per milliliter extrapolated to 3 days after detonation)	External theoretical maximum wholebody gamma infinity dose (roentgens)
Virgin River irrigation canal, Nevada	8.7×10^{-6}	6.0
Irrigation ditch, 56 miles north of Pioche, Nev	4.5×10^{-6}	.15
Lower Pahranagat Lake, Nev	3.2×10^{-6}	2.0
Virgin River at Mesquite, Nev	2.6×10^{-6}	2.5
Bunkerville, Nev. (tap water)	1.2×10^{-6}	7.0
Crystal Springs, Nev. (tap water)	1.1×10^{-6}	.15

Due to weather and to attenuation of the gamma rays by buildings, the wholebody gamma dose estimated to have been actually delivered was probably closer to one-half of the values shown.

The maximum permissible concentration of fission products in drinking water is $5 \times 10^{-3} \mu c/ml.$ extrapolated to 3 days after detonation. This is considered a safe concentration for continuous consumption.

Whereas, the monitoring of water sources is of value for documentary purposes it should be recognized that the concentrations found may vary widely within small geographical areas and even at the same location at different times (taking into account radioactive decay). Thus, confidence cannot be placed in precise values. Table VI-A suggests that even if one were to have stored up the water listed at Virgin River Irrigation Canal and subsisted entirely on this for a lifetime, the concentration would be about 58 times less than the maximum permissible amount. Normal factors of dilution by additional rainfall and/or by the influx of lesser contaminated ground water would be expected to reduce the level of activity.

Air.—Considerable effort has and is being made to evaluate hazards from airborne radioactive materials, including fission products. There are certainly many unanswered problems including the possible hazard from a single particle in

the lungs. Despite the uncertainties and as yet incomplete analysis of the inhalation hazard, the preponderance of evidence today is that the external gamma hazard from fallout is the more limiting factory of the two.[16] (However, see discussion on food contamination.)

During Upshot-Knothole quite complete data were collected of concentrations of airborne activity on about 150 occasions in some 40 different localities within 200 miles of the Nevada Proving Grounds. These included monitoring of all detonations. Histograms were made of air concentrations versus time after detonation for 30 occasions and estimates were made of doses to the lungs. These data for the five communities showing the highest air concentration are given in Table VI-B. The histogram for St. George (the highest 24-hour average concentration of fallout ever measured in a populated area) is reproduced in appendix J.

TABLE VI-B

Locality	24-hour average concentration (microcuries per cubic meter)	Dose to lungs (13 weeks) based on 20 percent deposition and 100 percent retention thereafter (mreps)[1]	Theoretical maximum whole-body gamma 13-week dose (roentgens)
St. George, Utah	1.29	130	3.5
Lincoln Mine, Nev	4.0×10^{-1}	12	1.5
Mesquite, Nev	1.7×10^{-1}	13	1.0
Groom Mine, Nev	3.4×10^{-2}	7	0.35
Pioche, Nev	2.0×10^{-2}	2	0.015

[1] The method used in estimating doses to the lungs is given in appendix K.

The criteria previously established by an Ad Hoc Jangle Feasibility Committee (Washington, D. C., July 13, 1951), for air concentrations were—

"At a point of human habitation, the activity of radioactive particles in the atmosphere, averaged over a period of 24 hours, shall be limited to 100 microcuries per cubic meter of air (corresponding approximately to a ground level gamma intensity of 30 mr. per hour).

"The 24-hour average radioactivity per cubic meter of air, due to suspended particles having diameters in the range 0 micron to 5.0 microns, shall not exceed one-hundredth of the above; nor is it desirable that any individual particle in this size range have an activity greater than 10^{-3} microcuries calculated 4 hours after the blast."

In the January 20, 1954, meeting of the ad hoc committee the basis for recommending the above air concentrations was discussed. Essentially, these criteria was selected by estimating the gamma dose that might be delivered by the passing of a radioactive cloud. Since there are better methods of estimating gamma doses and since there are uncertainties in evaluating the hazards of such transitory air concentrations as experienced from fallout, and since the preponderance of evidence from past nuclear test series indicates that the external gamma hazard is more limiting than the inhalation one, it was recommended in the January 20, 1954, meeting to strike from the record the past recommendations for maximum permissible air concentrations. It was recommended that an air monitoring program be continued for documentary purposes and for whatever value the data might have in the future when new analyses might be made in the light of additional knowledge.

A further discussion of the single particle problem may be made. In arriving at the recommendation" * * * nor is it desirable that any individual particle in this size range have activity greater than 10^{-3} microcuries calculated 4 hours after the blast" a computation was made that the average radiation dose from such a particle to a sphere one-half a millimeter in radius would be 385 reps.[17] However, the conclusions may be misleading. In the case of a single particle, relatively large doses are delivered near the particle and small doses at a greater distance. Appendix L suggests one possible estimate of this phenomenon. The

[16] Ad hoc committee meeting. Washington, D. C. Jan. 20, 1954.

[17] Minutes, Meeting of Committee to Consider the Feasibility and Conditions For A Preliminary Radiologic Safety Shot for Jangle. LASL. May 21-22, 1951.

parameters involved here are many and difficult to evaluate. For example, how long will a particle remain in one place in the lung and what dose will be delivered during that time?

It has been suggested that in the upper respiratory passage 20-micron diameter particles are the upper limit of size for deposition and that "Cilia sweep 4 to 6 cycles per second. The probability of a particle remaining within 1 millimeter zone for as much as one-half hour appears to be vanishing small. * * * Protection will also be provided by the mucus lining which is itself renewed several times an hour." Accepting the estimates above and the methods illustrated in appendixes E and F, it may be computed that about 8 reps would be delivered to the surface of an imaginary stationary sphere 1 millimeter in radius by a 20-micron particle (0.5 microcurie) in 30 minutes (appendix L). Larger doses will be delivered closer to the particle but with the relatively rapid movement of the particle, it does not appear that large doses will be delivered to a great number of cells. Multiple exposures might occur from additional particles but again this risk is difficult to evaluate.

Food.—Considerable effort is being directed toward the study of contamination of food from fallout. One element of major concern is Sr–90. It has been estimated that if one were to subsist entirely on food grown from soils containing about one-tenth to 1 microcurie per square foot of Sr–90 (1,000 pounds of calcium per acre to an average depth of 6 to 7 inches), that over a period of years there would accumulate in the human skeleton a body burden of 1 microcurie of Sr–90.[18] The highest Sr–90 activity found in soils from agricultural areas, about 100 miles from the Nevada test site, now shows a concentration of about 3.4×10^{-3} microcuries per square foot. This is a factor of 30–300 times less than the one-tenth to 1 microcurie of Sr–90 quoted above. The calcium content of soils around the Nevada test site is several times greater than the 1,000 pounds per acre used as a basis for calculations, which would materially reduce the strontium uptake.

(Although not of direct concern to the Nevada test site, it is of interest to note that soils were collected from the Marshall Islands following the fallout in early March 1954. Appendix M summarizes these data.)

A recent report strongly suggests that contamination of leaf surfaces followed by either direct consumption or intake by way of milk is a far more important pathway of intake than the soil-plant-animal cycle, at least for those times of year when plants may be in a state of growth to collect the fallout. Further analysis is being planned.

This same report raises a new problem. Based on stated assumptions, the data presented indicate relative doses of:

thyroid: tens of thousands of reps
Sr^{89-90}: 300 reps
external gamma: 40 roentgens

High radioiodine doses to the fetus and baby may be particularly important. Additional evaluation will be given this problem.

CRITERIA VI. ROUTINE RADIATION EXPOSURES

The whole-body gamma effective biological dose for off-site populations should not exceed 3.9 roentgens over a period of 1 year. This total dose may result from a single exposure or series of exposures.

If integrations of dose rate readings are used in estimating the effective biological doses, then table V may be used.

TABLE V

	Multiplication factor	Effective biological dose
Maximum theoretical radiation dose from time of fallout to 15 days later	¾	
Maximum theoretical radiation dose from 15th day to 1 year	½	
Total (best estimate of effective biological dose)		

[18] Private communication, L. A. Dean, U. S. Department of Agriculture, Beltsville, Md., April 28, 1954.

If film badges or dose meters are worn on personnel and the evidence of their use supports the view that the readings are a reasonably accurate account of the radiation dose received, then the values recorded on the film badge may be accepted with a correction factor of ¾ to account for the difference between the dose received by the film badges or dosimeters (including backscatter) and that received at the tissue depth of 5 centimeters.

CRITERIA VI. ROUTINE RADIATION EXPOSURES

Discussion

In 1953 the following recommendation was made in the report of Committee To Study Nevada Proving Ground:

"It is recommended, and found to be in conformity with the present principles of determining permissible exposure limits, that for test operation personnel the total body gamma exposure be limited to 3.9 r. in 13 weeks, and that the same figure be applied to the off-site communities with the further qualification in the latter case that this is the total figure for the year. In general, this implies a single test series in any given year."

On the basis of this recommendation and the reasoning discussed under criteria I, the criteria for estimating the whole-body gamma effective biological dose are summarized in table V. It will be noted that the biological factor included under criteria I is omitted in criteria V. In the first case we are dealing with relatively high doses that may require emergency measures with their attendant hazards. It is a situation where one wishes to estimate all pertinent factors in evaluating radiation doses even though they may not be known with preciseness, before recommending an emergency action that may produce greater problems. In the case of criteria V one is concerned with relatively lower doses during routine operations. It would be difficult to justify on the one hand the proposition that weekly doses for general populations may be integrated and taken in a single exposure without penalty and on the other hand, that a given dose received over a period of a year may be administratively reduced because of biological repair. Therefore, the biological factor is omitted.

The general effects of backscattering on measured radiation doses are fairly well established. Further, knowledge of depth (tissue)-dose curves has advanced to a quantitative state.[19] Thus, there seems to be little doubt that a film badge or dosimeter worn on the person will overestimate the gamma radiation dose delivered at a depth of 5 centimeters (assumed depth of blood-forming organs). A major factor in determining this difference is the quality of radiation under consideration. One report dealing explicitly with radiation in a fallout field suggests a factor of about ¾.

[19] Permissible Dose From External Sources of Ionizing Radiation. National Bureau of Standards Handbook 59. September 24, 1954.

APPENDIX A. SAMPLE ESTIMATION OF GAMMA DOSES SAVED BY REMAINING INDOORS

EXAMPLE I

Assume: Time of fallout = H+3 hrs
Dose rate at H+3 = 667 mr/hr

Then: Theoretical maximum dose from time of fallout to 3 hours later --- 1.30 r
Savings by remaining indoors for 3 hours --- 0.65 r
1 year effective biological dose if personnel did not remain indoors during the 3 hours (based on same assumptions contained in section on evacuation) --- ~5.5 r
Percent of 1 year effective biological dose saved by remaining indoors for the 3 hours --- ~12

EXAMPLE II

Assume: Time of fallout = H+3 hrs
Dose rate at H+3 = 667 mr/hr

Then: Theoretical maximum dose from time of fallout to 8 hours later --- 2.30 r
Savings by remaining indoors for 8 hours --- 1.15 r
1 year effective biological dose if personnel did not remain indoors during the 8 hours (based on same assumptions contained in section on evacuation) --- ~5.5 r
Percent of 1 year effective biological dose saved by remaining indoors for the 8 hours --- ~21

APPENDIX B. *Calculations of Beta Dose Rate at Depth of 7 Milligrams per Square Centimeter From a Thin Extended Source*

Assume: 1.5 Mev Beta (mean energy = 0.5 Mev)
$\mu = 10$ cm²/gm

(This assumes a single mass absorption coefficient.)

$$N = No\ e^{-\mu x}$$

where
No = number of betas at surface per cm² per sec.
N = number of betas at depth x
μ = mass absorption coefficient
x = distance (depth) under consideration

$$\frac{dN}{dx} = -\mu No\ e^{-\mu x}$$

$$R = \frac{\mu No\ e^{-\mu x} E}{2}$$

where
R = dose rate at depth x
E = mean energy of betas

$$R = \frac{(10) No\ e^{-(10)(0.007)}(0.5)}{2} = 2.33\ No \text{ Mev/gm-sec.}$$

$No = 3.7 \times 10^4 C$ where: C = activity in microcuries per cm²
$R = 8.65 \times 10^4 C$ Mev/gm-sec.
$R = (1.39 \times 10^{-1})(C)$ ergs/gm-sec.
$\cong 5.4\ C$ reps/hr
or $\cong 5.0\ C$ rads/hr

Example

Assume: $C = 80 \mu c/\text{cm}^2$ (beta)
$R = 5.4\ C$ where: R = dose rate at depth 7 mg/cm² in reps
C = activity/cm² in μc

$= (5.4)(80)$
$= 432$ reps/hr
or $= 400$ rads/hr

Comparison Beta Dose Rate (Reps/hr) at 7 Mg/cm² to Gamma Dose Rate Measured in Infinite Field at 3 Feet Above the Surface

Assume: 80 $\mu c/cm^2$ (beta), equivalent to 1 megacurie/mi^2 (gamma)

$$\frac{432}{4.1} \cong 105$$

Appendix C. *Experimental Data Versus Theoretical Calculations (Appendix B) in Estimating Beta Doses*

In one relevant experiment, a thin P^{32} source was prepared by soaking a filter paper in a solution of phosphates and allowing it to dry. The surface dose rates were then measured with a surface ionization chamber.[1] Pertinent data are abstracted as follows:

Thickness of source	9.6 mg/cm^2
Activity of source	77.0 $\mu c/cm^2$
Surface dose rate	0.127 rep/sec; 457 reps/hr
Dosage rate at depth of x centimeters	$e^{-9.5x}$

A. Theoretically:

Using the equation from Appendix B

$$R = \frac{\mu N o e^{-\mu x} E}{2} \text{ (for } P^{32}\text{)}$$

Substituting above data:

$$R = \frac{9.5 N o e^{-(9.5)(0.007)} .69}{2}$$

$$= 7.0\ C \text{ reps/hr}$$

$$\text{Let } C = 77\ \mu c/cm^2$$

$$\text{Then } R = 7.0 \times 77$$

$$= 539 \text{ reps/hr at 7 mg/cm}^2\ (P^{32})$$

B. Experimentally:

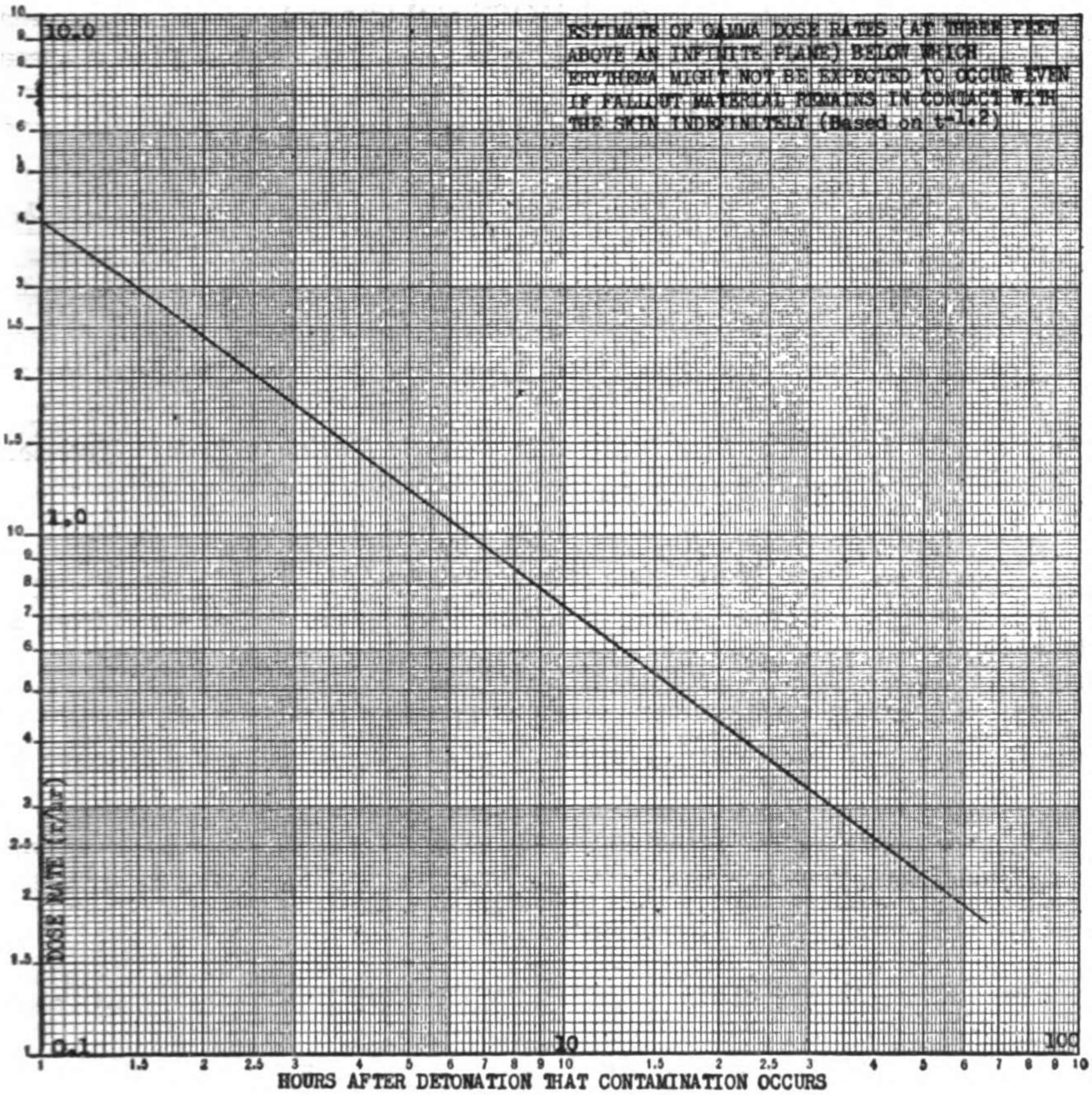
$$R = 457\ e^{-(9.5)(0.007)}$$

$$= 427 \text{ reps/hr at 7 mg/cm}^2\ (P^{32})$$

The two above approaches are within 26 percent of each other. If one extrapolates the experimental data from a source of 9.6 mg/cm^2 to a thin source (for comparative purposes) the two methods are within 20 percent.

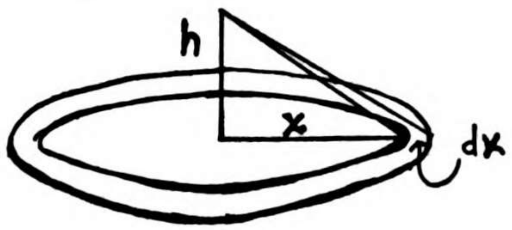
[1] *Effects of External Beta Radiation.* Zirkle, Raymond E. McGraw-Hill Book Co. 1951.

APPENDIX C (a)



Appendix D. *Calculations Gamma Dose Rate From a Field 6 Inches in Radius and Center of Chamber 4 Inches Above Surface*

Dose rate of gamma from a point source:



$r \cong 6CE$ where: r = r/hr
C = activity in curies per square foot
E = average energy of gammas (Mev)

$$D = 6CE\, 2\pi \int_0^x \frac{x\,dx}{h^2 + x^2}, \text{ where } D = \text{dose rate in r/hr}$$

$$D = 18.8\ CE \ln \left[\frac{h^2 + x^2}{h^2}\right]$$

Example:

Let: $x = 1/2$ foot
$C = 40\mu c/cm^2$ or 3.6×10^{-2} c/ft² (gamma)
$E = 0.7$ Mev
$h = 1/3$ foot

$$D = (18.8)(3.6 \times 10^{-2})(0.7) \ln \left[\frac{(1/3)^2 + (1/2)^2}{(1/3)^2} \right]$$
$$= 0.56 \text{ r/hr}$$

Comparison Gamma Dose Rates From Infinite Plane at a Height of 3 Feet Above the Ground to Area of 6-Inch Radius and Height of 4 Inches

Assume: 1 megacurie/mile²
(3.6×10^{-2} c/ft²)

$$\frac{4.1 \text{ r/hr}}{0.56 \text{ r/hr}} = 7.3$$

Appendix E. *Estimate of Dose Delivered by a Single Particle of Fallout Material*

Assume: a. Point source
b. 0.5 Mev average beta energy
c. $\mu = 10$ cm²/gm
d. Rate of decay follows $t^{-1.2}$

The dose delivered at the surface of an imaginary sphere at distance R from a point source.[1]

(1) $$K(R) = \frac{CE\mu}{4\pi R^2} e^{-\mu R} \frac{\text{Mev}}{\text{gram}}$$

where: $K(R)$ = dose delivered at the surface of an imaginary sphere at distance R
E = average energy of beta particles
C = total number of disintegrations
μ = mass absorption coefficient

Substituting:

$\mu = 10$ cm²/gm
$E = 0.5$ Mev

Then: (2) $$K(R) = 0.4 \frac{e^{-10R}}{R^2} \frac{\text{Mev}}{\text{gm-disintegration}}$$

or (3.a.) $$K(R) = 6.9 \times 10^{-6} \frac{e^{-10R}}{R^2} \frac{\text{millireps}}{\text{disintegration}}$$

or (3.b.) $$K(R) = 6.4 \times 10^{-6} \frac{e^{-10R}}{R^2} \frac{\text{millirads}}{\text{disintegration}}$$

Note.—Equation (3.a.) is plotted on the attached graph.

For fission products:

(4) $$A_a = A_1 t_a^{-1.2}$$

where: A_a = disintegrations per unit time at time "a" after detonation
A_1 = disintegrations per unit time at one unit of time after detonation

Integrating equation (2),

(5.a.) $$C = 5A_1(t_a^{-0.2} - t_b^{-0.2})$$
and (5.b.) $$C = 5A_a t_a^{1.2}(t_a^{-0.2} - t_b^{-0.2})$$

where: C = total number of disintegrations from time "a" to "b"
t_a = time after detonation
t_b = later time after detonation.

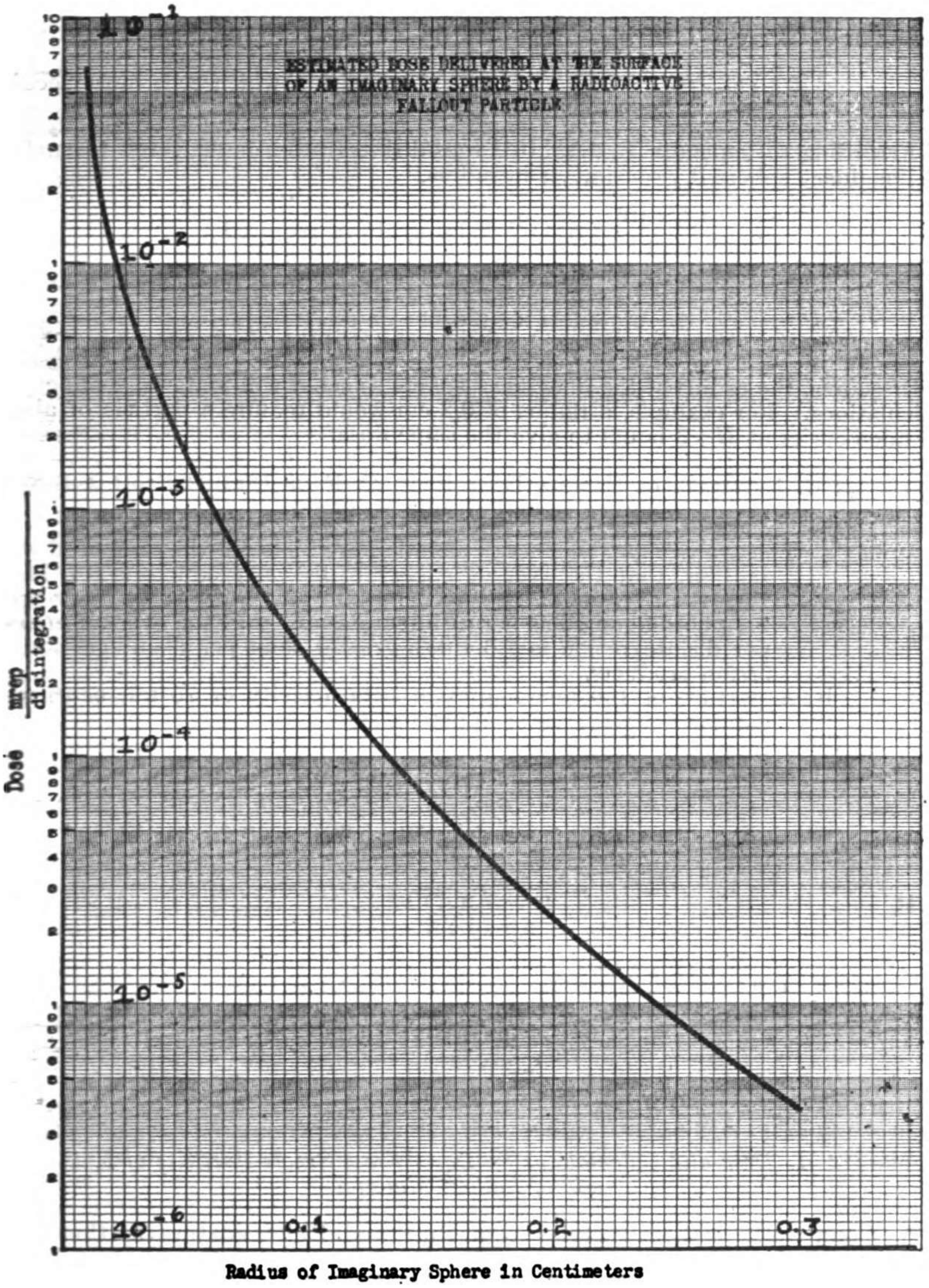
When t_b is infinite,

(6) $$C_\infty = 5A_t t.$$

By the use of equations (3.a.) or (3.b.) and (5.b.) one may compute an estimated dose at the surface of an imaginary sphere.

Of course, the problem is the determination of "t_a" and "t_b", i. e., how long after detonation will a radioactive particle be deposited and how long will the particle remain in place. The first time (t_a) is much easier to estimate than the later (t_b).

[1] Rossi, H. H. and Ellis, R. H. "Distributed Beta Sources in Uniformly Absorbing Media.". *Nucleonics.* July 1950. V. 7 No. 1.



ESTIMATED DOSE DELIVERED AT THE SURFACE OF AN IMAGINARY SPHERE BY A RADIOACTIVE FALLOUT PARTICLE
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0.1
0.2
0.3
Dose $\frac{\text{mrep}}{\text{disintegration}}$
Radius of Imaginary Sphere in Centimeters

APPENDIX F. ESTIMATE OF BETA DOSES FROM A SINGLE PARTICLE ON THE SKIN (POSSIBLE PRODUCTION OF RECOGNIZABLE ERYTHEMA)

Let: $t_a = 3$ hours (time particle is deposited on skin)
$t_b = 27$ hours (time particle is removed)

Assume: 1500 reps = total dose required in one day to produce recognizable erythema
0.1 cm = radius of imaginary sphere within which cells must receive 2000 reps or larger.

According to appendix E, 2.5×10^{-7} reps/disintegration is delivered to surface of imaginary sphere 0.1 centimeter in radius.

$$\frac{1.5 \times 10^3}{2.5 \times 10^{-7}} = 6 \times 10^9 \text{ disintegrations required}$$

$$C = 5A_a t_a^{1.2}[t_a^{-1.2} - t_b^{-0.2}]$$

$$6 \times 10^9 = 5A_a 3^{1.2}[3^{-0.2} - 27^{-0.2}]$$

$$A_a = 1.14 \times 10^9 \text{ d/hr}$$

or about 8.6 μc at $H+3$ hours.

Of course, the radius of the imaginary sphere selected will materially affect the calculations. For example, a radius of 0.2 cm would require a particle of about 96 microcuries at $H+3$ hours to give the same dose.

APPENDIX G. ESTIMATE OF GAMMA DOSE RATE AT FOUR INCHES FROM A SINGLE PARTICLE OF FALLOUT MATERIAL

Assume: a. The average gamma energy of fission products may be compared with radium; that the average energy of fission products is 0.7 Mev; that the average energy from radium daughters is 0.8 Mev with 2.3 photon emissions per disintegration or that the average energy per disintegration is 2.6 times greater than per disintegration of fission products.

b. A particle of 150 microcuries of beta activity or 75 microcuries of gamma activity. (See appendix H.)

$$I = \frac{8.4 \text{ mg (mc)}}{d^2} \text{ for radium through 0.5 mm of platinum.}$$

where: I = gamma dose rate (r/hr)
d = centimeters

Let: $mc = 7.5 \times 10^{-2}$
$d = 10$ cm

$$I = \frac{(8.4)(7.5 \times 10^{-2})}{10^2}$$

$= 6.3$ mr/hr gamma dose rate at 4 inches (for radium)

$$\frac{6.3}{2.6} \cong 2.4 \text{ mr/hr for fission products}$$

APPENDIX H. *Data and Calculations on Doses From Single Particles of Ruthenium and of Fallout Material*

A. Comparison of beta energies from Ru^{103} and Ru^{106} mixture to that from fission products.

Ru^{103} 0.3 Mev beta ($T = 42$d.)
Ru^{106} ~0.03 Mev beta ($T = 1.0$y.)
Rh^{106} 3.55 Mev beta ($T = 30$s.)

Assume: Ru^{103}/Ru^{106} ratio of 0.75 [1]

[1] All of the basic data contained herein on ruthenium is contained in HW-33068. A status report. Sept. 15, 1954.

To estimate a mean average energy of betas from mixture:

Parts	Isotopes	Maximum energy beta	Weighted maximum energy betas
1.0	Ru^{103}	0.35	0.35
1.33	Ru^{106}	0.04	0.05
1.33	Ru^{106}	[1] 3.35	4.45
Total			4.85

[1] Average.

$$\frac{4.85}{3.66} \cong 1.3$$

Average energy ~0.43 or roughly equivalent to that assumed for fission products.

(Of course, the average energy of the betas is not the sole consideration. The spectral distribution of the betas from Rh^{106} probably is quite different from that of fission products, thus affecting the depth dose curve.)

B. Data on doses and effects from single particles of Ru^{103} and Ru^{106}:

	a	b
1. Size of particle	40 μ	120 μ.
Activity of particle	1.1 μc	11 μc.
Dose rate to 7 mg/cm²	6,000 rads/hr	27,500 rads/hr.
Time dose delivered	~6 days	~6 days.
2. Survey dose rate (mrads/hr)[1]	**Total skin dose (rads)[2]**	**Effects**
400	~500,000	None visible.
750	~900,000	Reddening.
2,500	~2,000,000	Desquamation.
11,000	~6,000,000	Tissue destruction.
21,000	~7,000,000	Tissue destruction—2 cm across. 8 mm deep.

[1] 90 mrads/hr≅1 μc.
[2] "Total dose refers to the hot spot directly below the particle, and is valid only as to order of magnitude."

C. $\frac{750}{90} \cong 8.3$ μc estimated activity of particle producing reddening effect in about 144 hours. The estimated size is 100 microns.

D. (8.3) (144) = 1200 μc total activity accounted for in the 144 hours that the dose was delivered. (Assuming constant activity during the 144 hours.)

E. What specific activity of a particle of fallout would be required to deliver the same dose in the same length of time?

The answer to this question depends upon the time after detonation that the particle comes in contact with the skin. Assuming this time to be H+3 hours, the specific activity would have to be about 150 μc for the same size particle.

Since the particle may be washed off before 6 days have expired, one may consider the problem another way. What must be the specific activity of a particle at H+3 hours to deliver this dose in the next 24 hours?

According to Strandgvist (p. 6), only about 70 percent of a 6-day dose need be delivered in one day to produce the same effect (erythema). Accepting this, then a particle with about the same activity (160 μc) at H+3 hours would be sufficient to deliver an erythema dose in 1 day.

F. The following data are reported for single particles collected during Upshot-Knothole and Tumbler-Snapper.

Size of particle (μ)	Activity extrapolated to H+3 hours (μc)	Distance from ground zero (miles)
[1]	1,000	45
[1]	200	130
1,626 x 924	900	10
919	480	11
723	350	14.7
714	400	10
555	140	14.7
387	250	14.7
234	47	14.7
115	5.2	9.5
81	3.0	14.7
20	.5	------------

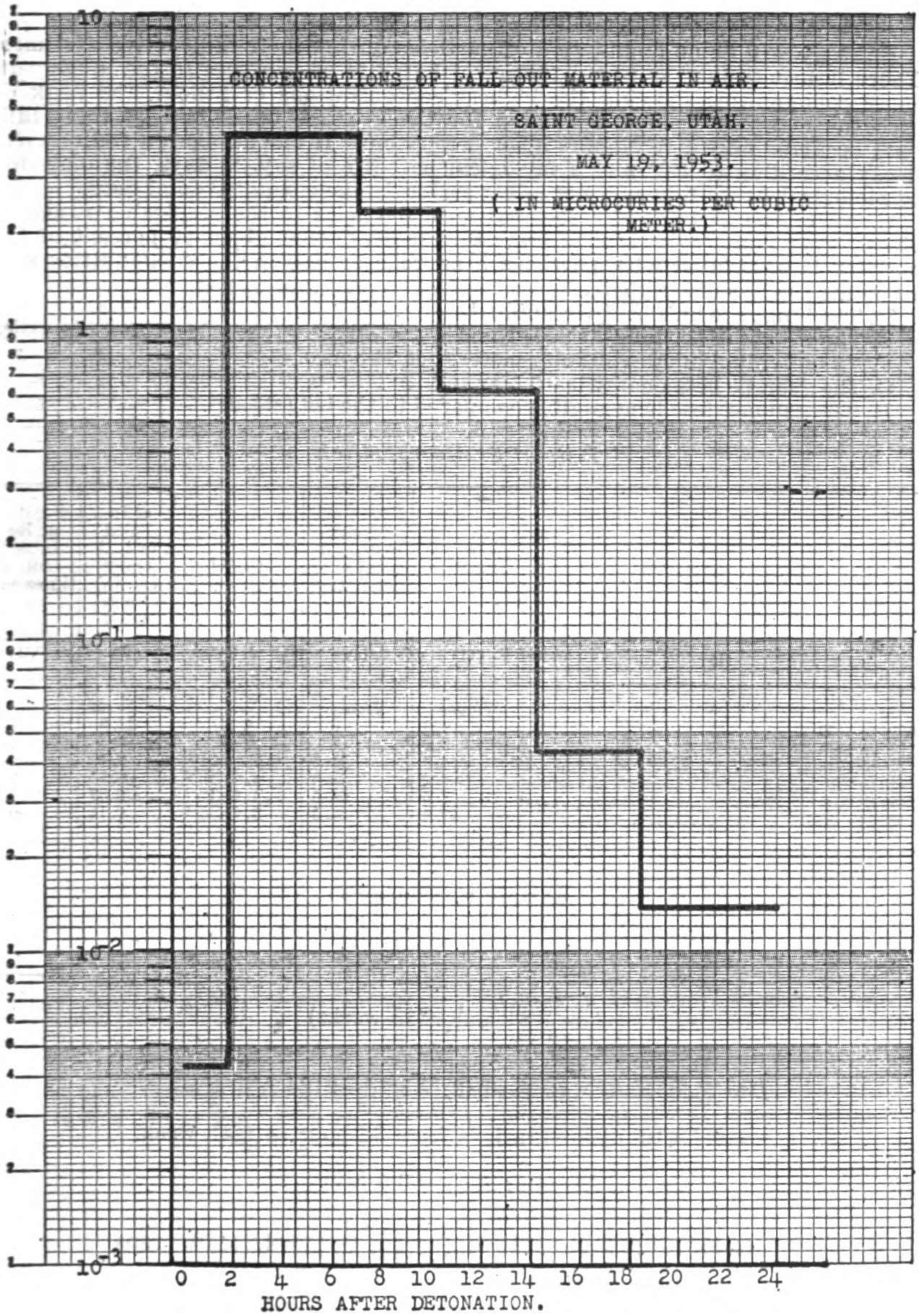
[1] Data from estimations based on radioautograph methods.

It is not intended here to imply these are the maximum specific activities per particle that existed or could exist. The data at 14.7 miles are reported to show the wide range of specific activity that may occur at one locality.

Appendix I. Estimation of Ratio of Surface Beta Dose Rate to Gamma Dose Rate at 4 Inches from an Object 2 Inches in Radius

One may assume a ratio of beta dose rate (at 7 mg/cm^2 depth of skin) to gamma dose rate (3 feet above the ground) of 125/1. If a contaminated object of say 2-inch radius were removed (or shielded) from a general radiation field the gamma dose rate at 4 inches from the surface might be some 40 times less than from an infinite plane with the same degree of contamination (appendix D), while the beta dose rate might remain almost the same value if the object is in contact with the skin. Thus, the beta-to-gamma dose rates measured under these conditions might be 5,000–1. For other than a plane surface, the gamma dose rates might be higher, thus reducing this ratio.

APPENDIX "J"


CONCENTRATIONS OF FALL OUT MATERIAL IN AIR.
SAINT GEORGE, UTAH.
MAY 19, 1953.
(IN MICROCURIES PER CUBIC METER.)
10
1
10^{-1}
10^{-2}
10^{-3}
0 2 4 6 8 10 12 14 16 18 20 22 24
HOURS AFTER DETONATION.

Appendix K. Method Used in Estimating Doses to the Lungs from Inhalation of Fallout Material

Assumptions

The following assumptions are made in estimating radiation doses to the lungs.

A. Twenty percent of the inhaled activity is deposited.

B. There will be no elimination of particles during their radioactive lifetimes. There is uncertainty as to the biological half life of particles in the lungs. In those communities showing the highest concentrations of fallout, the peak of airborne material (which accounted for the greatest percentage of total fallout) occurred only a few hours after detonation. If one assumes a radiological decay according to $t^{-1.2}$ and a biological half life of say 30 days, the omission of biological half life would not affect seriously the computed total dose.

C. All of the activity is associated with particles in the respirable range of sizes. Past data from cascade impactors indicate that about 90 percent of the activity is associated with particles 5 microns or less in the communities surrounding the Nevada test site.

D. The lungs are uniformly irradiated.

E. The weight of the lungs is 900 grams.

F. An individual inhales 20 cubic meters per 24 hours.

G. The average beta energy is 0.5 Mev.

H. The gamma dose is negligible compared to the beta dose.

Data at St. George, Utah

(Short time) 0505 (I)	Duration (II)	Approximate midpoint after detonation III	[1]$\mu c/M$ (IV)	μc Inhaled (col. II times col. IV times 0.834) (V)	μc Retained (col. V times 0.2) (VI)
	Hours	*Hours*			
0610 to 1130	4.3	3	4.17	15.0	3.0
1130 to 1445	3.2	8	2.38	6.3	1.26
1445 to 1845	4.0	11.5	6.3×10^{-1}	2.1	0.42
1845 to 2300	4.2	15.6	4.4×10^{-2}	0.15	0.03
2300 to 0635	7.5	21.5	1.4×10^{-2}	0.09	0.02
[1]0635 to 1835	12.0	31.5	1.4×10^{-2}	0.14	0.03

[1] Assumed.

Sample calculations

$$D=5At_a^{1.2}[t_a^{-0.2}-t_b^{-0.2}]$$

Let: $t_a=3$ hours
$t_b=2184$ hours (13 weeks)
$A=3\ \mu c$

$$D=(5)(3\times2.22\times10^{6}\times60)(3)^{1.2}[3^{-0.2}-2184^{-0.2}]$$

$$=4.4\times10^{9}\text{ disintegrations from 3d hour to 13th week.}$$

Assume: $E_{avg.}=0.5$ Mev

$$(4.4\times10^{9})(0.5)(1.6\times10^{-6})\left(\frac{1}{900}\right)\left(\frac{1}{39}\right)=4.2\times10^{-2}\text{ reps}$$

$$=42\text{ mreps}$$

Total lung dose for 13 weeks: $\sim$130 mreps.

APPENDIX L. ESTIMATE OF DOSE AT SURFACE OF IMAGINARY SPHERE 1 MILLIMETER IN RADIUS

Assume: Average activity for 30 minutes is 0.5 μc at H+3 to H+3½ hours. (See reference appendix H.)

Then: $0.5 \times 2.2 \times 10^6 \times 30 = 3.3 \times 10^7$ disintegrations/30 minutes.

At surface of imaginary sphere 1.0 mm. in radius the dose rate from a point source is

$$2.52 \times 10^{-4} \frac{\text{mreps}}{\text{disintegration}} \text{ (See appendix E.)}$$

$$(3.3 \times 10^7((2.52 \times 10^{-4}) = 8.3 \times 10^3 \text{ mreps/30 min.}$$
$$\cong 8 \text{ reps/30 min.}$$

For particles of higher specific activity, the dose would be correspondingly higher, of course.

APPENDIX M

Estimate of Sr^{90} in soils of Pacific islands

Location	Total activity ($\mu c/ft^2$) (measured) I	Sr^{89}–Sr^{90} ($\mu c/ft^2$) (measured) II	Rough estimate external infinity gamma dose (roentgens) III
Likiep [1]	1.2×10^{-1}	8.7×10^{-3}	4
Jemo	3.0×10^{-1}	1.2×10^{-2}	4
Ailuk	1.0	3.8×10^{-2}	12
Mejuit	1.1	2.8×10^{-2}	8
Ormed	3.2×10^{-1}	1.1×10^{-2}	4
Kaven	1.6×10^{-1}	4.8×10^{-3}	2
Wotho	7.8×10^{-2}	1.3×10^{-3}	0.5
Rongelap:			
(Northern)	62.0	1.08	500
(Central)	40.0	5.5×10^{-1}	500
(1 mi. N. Village)	5.0	5.3×10^{-1}	500
(So. Cistern)	4.5	9.2×10^{-1}	500
Erlirippu [1]	230.0	12.5	4,500
Eniwetok	50.0	1.2	1,500
Kabelle	200.0	4.9	3,300
Utirik	53.0	9.8×10^{-2}	60
Bikar	3.3	4.4×10^{-1}	250
Eniwetok	8.0	6.6×10^{-1}	400
Sifo	6.1×10^{-1}	9.6×10^{-3}	170

[1] All data as of May 5, 1954, except island of Erlirippu where date is May 20, 1954.

UNITED STATES ATOMIC ENERGY COMMISSION,
Washington D. C., August 2, 1957.

Hon. CHET HOLIFIELD,
Chairman, Special Subcommittee on Radiation,
Joint Committee on Atomic Energy,
Capitol Building, Senate Post Office, Washington, D. C.

DEAR MR. HOLIFIELD: As a part of the written record of The Nature of Radioactive Fallout and Its Effects on Man, there is being reproduced a document Discussion of Radiological Safety Criteria and Procedures for Public Protection at the Nevada Test Site written by me some time ago. I would greatly appreciate it if a footnote (attached) were added to this document.

Also enclosed is a copy of the revised radiological safety criteria (April 1957) that are currently being used. I would like to suggest respectfully that these revised criteria also be printed so that the reader may have the benefit of our latest thinking on these matters.

Sincerely yours,

GORDON M. DUNNING,
Health Physicist, Division of Biology and Medicine.

Radiological Safety Criteria During Nuclear Weapons Testing at the Nevada Test Site

(April 1957)

INTRODUCTION

The criteria and procedures set forth in the following paragraphs were established after full consideration for protecting the health and welfare of the public, both in terms of radiological exposure as well as possible hazards, hardships or inconveniences resulting from disruption of normal activities. Criteria are established as guides for the Test Organization in determining whether any special actions should be taken to protect the public.

These criteria are not established with the expectation that the coming tests at the Nevada Test Site actually will result in radiation levels which will be greater than heretofore. Rather, they formalize past criteria to give even clearer guides for protecting the public. With improved methods of predicting fallout and with the use of balloons and higher towers for detonating the nuclear devices, it is expected that fallout in populated areas from future tests at the Nevada Test Site will be less than the highest amounts which have occurred in the past.

Two basic assumptions are made in this report:

(*a*) It is the responsibility of the Division of Biology and Medicine to establish such criteria for the Atomic Energy Commission as deemed necessary to protect the health and welfare of the general populace from consequences of weapons tests conducted at the Nevada Test Site.

(*b*) The operational procedures adopted for meeting these criteria shall be the responsibility of the Test Manager, as directed by the Division of Military Application, with the technical guidance of the Division of Biology and Medicine.

The following criteria do not apply to domestic or wild animals since levels of radiation which would be significant to them would have to be higher than those specified herein.

Section I. Evacuation

BACKGROUND

The decision to evacuate a community is critical for two principal reasons. One, presumably there might be a health hazard if the personnel were allowed to remain. Two, there is always an element of danger and/or hardship to personnel involved in such an emergency measure.

It is recognized that extenuating circumstances may accompany any situation where conditions indicate evacuation as a mode of action. The size of the community, areas and accommodations available for the evacuees, weather conditions, means of transportation and routes of evacuation, disposition of ambulance cases, protection of the property left behind, and many other factors may enter into the decision relative to evacuation. Further, it is recognized that under certain conditions, the evacuation of a community might prove not only rather ineffectual but could result in more radiation exposure than if the population remained in place unless the situation be adequately evaluated. A blanket evaluation cannot be made in advance; each situation can be unique. The following criteria therefore are suggested as guides in assessing the possible radiological hazards; the final decision must be made on the basis of all relevant factors known at the time. They are intended to apply principally to relatively large populations since small groups may be evacuated without equivalent potential hazards.

Owing to the necessity of making early measurements and decisions, it is to be expected that dose-rate readings, taken with survey meters, will be the available evidence at the times of concern. This necessitates making rough approximations in advance of the effects of weathering and of shielding from normal housing, in reducing the radiation exposure. The variable nature of these two parameters makes impossible the establishment of a precise rule covering all situations. Therefore, the following may be used in making conservative estimates of these effects:

(*a*) For weathering—the measured gamma dose rates at three feet above the ground be assumed to decay according to $(t)^{-1.2}$ for the first week after a detonation, $(t)^{-1.3}$ for the second week, and $(t)^{-1.4}$ thereafter.[1]

(*b*) For shielding—the accumulated dose per day be 25% less than the out-of-doors dose.[2]

In the case of a truly emergency situation where potential hazards may exist either from the fallout or from mass evacuation of large populations, it would seem proper than due consideration be given to the biological repair process that takes place with radiation doses distributed in time (recognizing that such effects from radiation as genetic changes and life shortening may not be time dependent). The estimates for biological repair for man are quite uncertain so a conservative value is used here of a half-time of repair of about four weeks.

Graph I incorporates the above factors of weathering, shielding, and biological repair into a single curve. This graph may be linearly extrapolated to other dose rate readings. For example, if fallout occurs three hours after detonation and the dose rate is 10 r per hour, then about 67 r (effective biological dose) may be accumulated, i. e., $\frac{10}{0.15}\times 1.0=67$

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[1] This concept was suggested after analyzing data from both the Nevada Test Site and the Eniwetok Proving Ground and is intended to give generalized estimates to cover a wide variety of situations. It is recognized that with the smaller fallout patterns and with the sandy soils around the Nevada Test Site, the effective decay constants may be greater than these. An expanded monitoring program will be in operation during Operation Plumbbob (1957 Series) for the collection of pertinent data to allow better estimates of effective rates and of the efforts of shielding provided by buildings.

[2] This is based on an average 12 hours per day stay in a frame house having an attenuation factor of two. It is recognized that some individuals will be in buildings having higher attenuation factors, and for longer periods of time. On the other hand, this is generally an area where people may live an appreciable amount of time out of doors and where windows and doors are left open, so the fallout material may enter the buildings. Possible revision of these estimates will await results from the expanded monitoring program during Operation Plumbbob.

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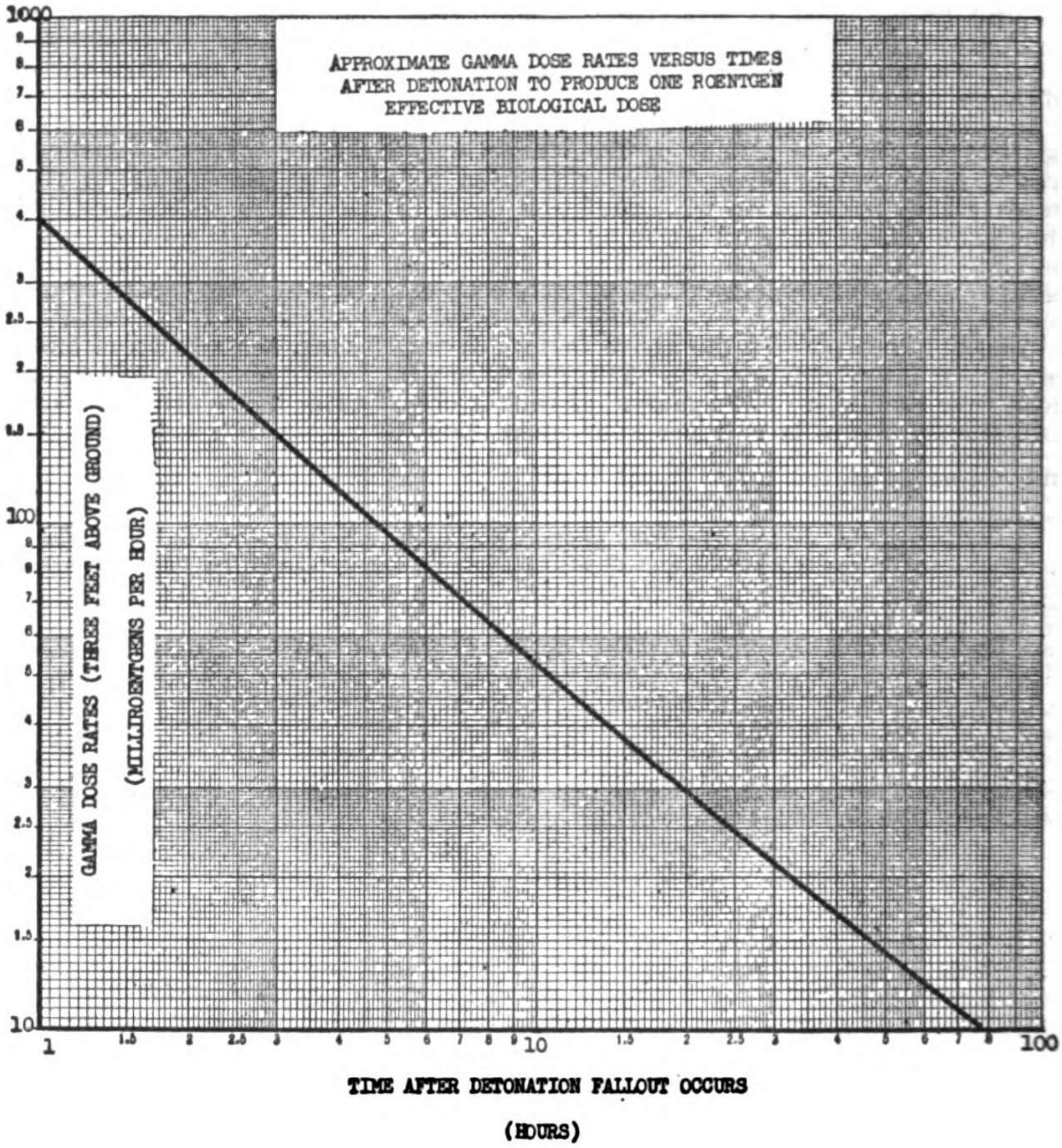
GRAPH I



CRITERIA I

Effective Biological Doses may be calculated according to Graph I.

Table I may be used in evaluating the feasibility of evacuating relatively large populations.

TABLE I.—*Radiological criteria for evaluating feasibility of evacuation*

Effective biological dose:	Minimum effective biological dose that must be saved by act of evacuation (otherwise evacuation will not be indicated):
Up to 30 roentgens	(No evacuation indicated.)
30 to 50 roentgens	15 roentgens.
50 roentgens and higher	(Evacuation indicated without regard to quality of dose that might be saved, providing adequate shelters are not available and the estimated hazards concomitant with evacuation are acceptable.)

SECTION II. PERSONNEL REMAINING INDOORS

BACKGROUND

By remaining indoors (*a*) the gamma exposure will be reduced, and (*b*) there is less possibility that the fallout material will come into contact with the skin. (Beta burns have occurred in the past only when the fallout material has remained in direct contact with the skin.) To prevent or greatly reduce this latter effect, it is highly desirable to make decisions before or very shortly after the start of the fallout. Likewise, partial shielding at these early times will be of optimum benefit due to the relatively high gamma dose rates. Thus, the decisions must be based on predicted fallout in an area, or on dose-rate readings from field monitors' reports.

These predictions are of course subject to varying degrees of uncertainly so that personnel may be asked to remain indoors unnecessarily. On the other hand decisions and action must be taken relatively quickly if optimum benefits are to be derived and remaining indoors until the radiological information is more accurately evaluated probably represents one of the easiest and effective ways of meeting an emergency situation.

Due to uncertainties in our knowledge, and recognizing the usual unequal distribution of fallout, it has not been possible to establish precisely the amount of fallout in an area that could produce beta burns. The Marshallese experience showed such effects for those people exposed to 175 r and 69 r whole body gamma radiation, but none for those individuals on the Island of Utirik (370 miles from ground Zero) receiving 14 roentgens. Whether these results would hold true for other situations is not known, i. e., different particle size distribution, different type skin, etc. At one location, Riverside Cabins, Nevada, about 15 people were in an area receiving fallout in an amount equivalent to infinity dose of 15 roentgens, with no known cases of beta burns, although it is not known if anyone was out-of-doors during the time of fallout. Until more is learned of this phenomenon, it would appear advisable to remain out of the direct fallout when the amount would be such as to produce about 10 roentgens gamma infinity dose as measured at three feet above the ground. In the event personnel are out of doors during the time of this amount of fallout, the possibility of beta burns could be greatly reduced by the simple expedient of changing clothing and of bathing.

If people were not asked to remain indoors during the period of highest dose rates in an area where the infinity dose was 10 roentgens or more, their actual exposure might be in excess of 3.9 roentgens of wholebody gamma. This would not necessarily be hazardous but would exceed the established criteria for Plumbbob (Criteria VI).

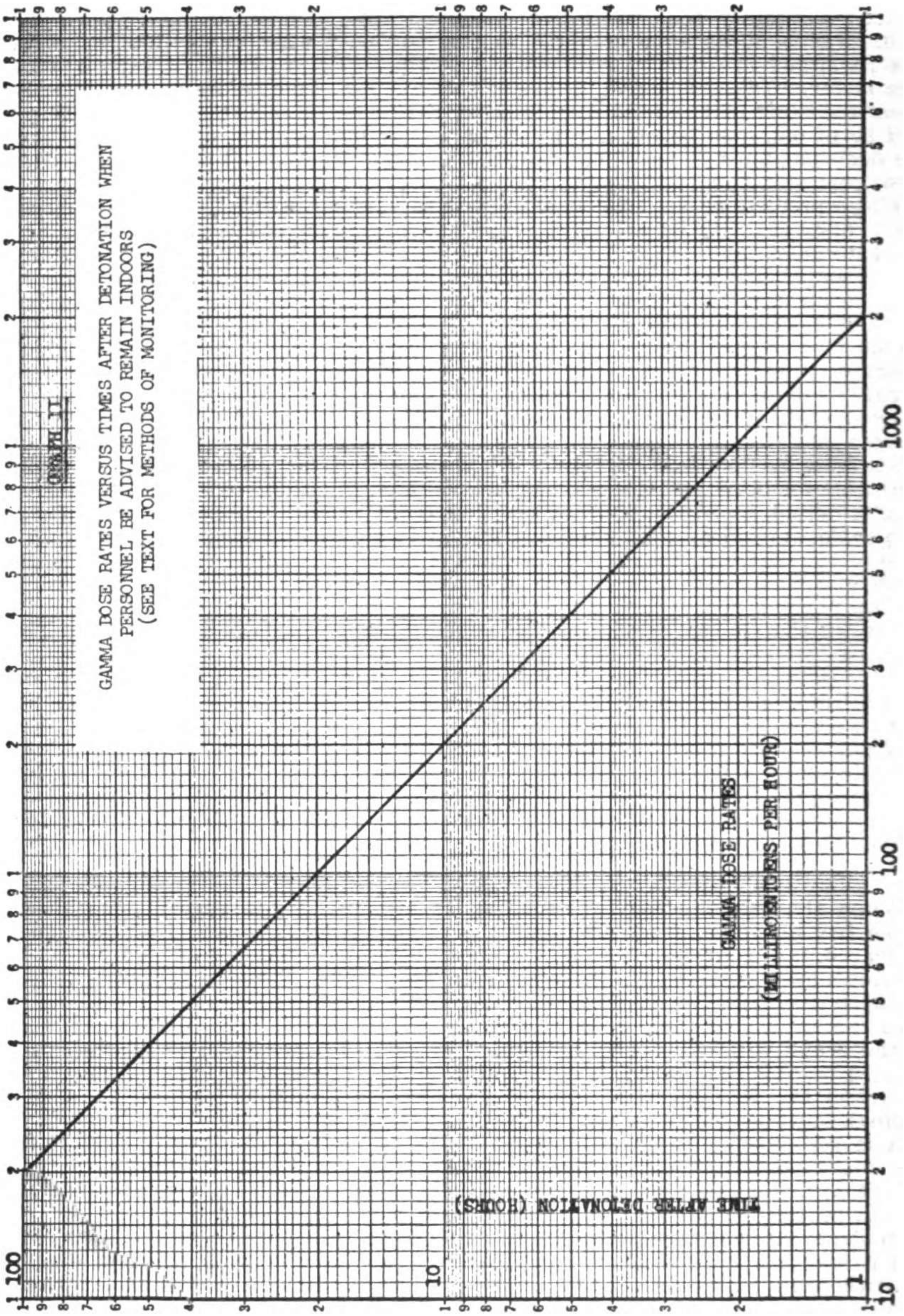
CRITERIA II

When the gamma dose rate reading as measured by a survey meter held three feet above the ground reaches the values given in Graph II at the times indicated, it is recommended that personnel be requested to remain indoors with windows and doors closed. Release from this restrictive action should be made on the basis of further evaluation of the radiological conditions.

In the event that there be convincing evidence that the radiation levels given in the graph will be reached, it is recommended that personnel be requested to remain indoors BEFORE fallout occurs or before the radiation levels equal those in Graph II. Release from this restrictive action should be made on the basis of further evaluation of the radiological conditions.

It is recommended that people who had been out of doors during fallout of the above magnitude or greater be advised to change clothing and to bathe. The clothing may be cleaned by normal means. While bathing, special attention should be paid to the hair and any exposed parts of the body.

In the event that the monitoring takes place AFTER the fallout has occurred, and extrapolation of the dose rate readings equals or exceeds those in Graph II at the estimated time of fallout, then it is recommended that the same advice be given as in the preceding paragraph.


GRAPH II
GAMMA DOSE RATES VERSUS TIMES AFTER DETONATION WHEN
PERSONNEL BE ADVISED TO REMAIN INDOORS
(SEE TEXT FOR METHODS OF MONITORING)
GAMMA DOSE RATES
(MILLIROENTGENS PER HOUR)
TIME AFTER DETONATION (HOURS)
10
100
1000
1
10
100

SECTION III. DECONTAMINATION OF PERSONNEL

BACKGROUND

The principal purposes for decontaminating personnel are to reduce the potential beta doses to the skin, and to a lesser degree reduce the external gamma exposure. The discussion on beta doses in Section II is applicable here. In addition, there is much unknown about monitoring methods for personnel contamination. The following criteria were previously developed on the basis of measuring the gamma radiations (and then extrapolating to the accompanying beta radiations) with existing instruments. Recently new field instruments have been developed for direct beta measurement, but there remains considerably more work necessary to calibrate them in terms of beta dose rates to the body. Until this is accomplished, the past criteria may be used.

CRITERIA III

Where it is not possible to monitor personnel outside of a general radiation field, it is recommended that an estimate be made of the degree of personnel contamination by determining the location of the individual at the time of fallout. In the event there is uncertainty as to the validity of such an estimate, the assumption will be made that the individual was out-of-doors during the time of fallout. In those areas where the infinity gamma dose equals or exceeds 10 roentgens, it is recommended that the individual be advised to bathe and to change clothing.

For personnel being monitored outside the general radiation field where personnel contamination exists over relatively large areas of the EXPOSED body (one-half square foot or more):

When the reading of a survey instrument held with the center of the probe or center of the ionization chamber four inches from the center of the contaminated area, equals or exceeds the values given in Graph III it is recommended that personnel be advised to bathe and to change clothing.

For personnel being monitored outside the general radiation field, where personal contamination exists over relatively small areas of the EXPOSED body (less than one-half a square foot):

The recommended maximum values are one-half those given in Graph III. Monitoring of the head, arms, hands, lower legs, and feet will be considered as coming under this category. Washing may be limited only to the contaminated parts, and also a change of clothing may not be indicated, unless the radiation levels exceeds those stated below concerning monitoring of exterior surfaces of clothing.

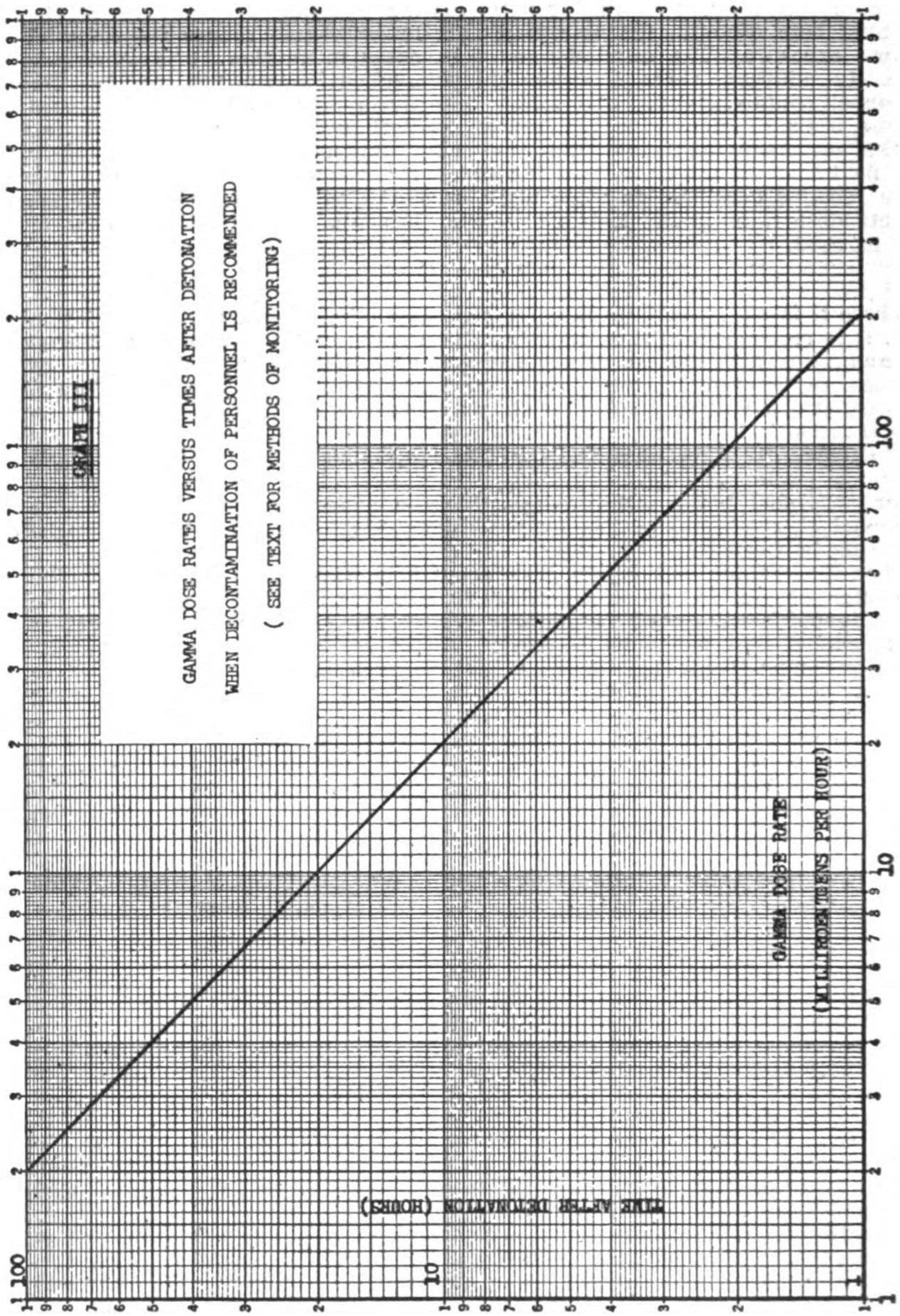
For personnel being monitored outside the general radiation field, and the contamination exists over only spots of EXPOSED body (about the size of a half-dollar or less):

The recommended maximum values are one-fifth those given in Graph III. Washing may be limited only to the contaminated parts, and also a change of clothing may not be indicated unless the radiation levels exceed those stated below concerning monitoring of exterior surfaces of clothing.

For personnel being monitored outside the general radiation field and the contamination exists over any size area on the exterior surface only of the clothing:

The recommended values under these conditions are twice those given in Graph III. The first recommended action shall be to resort to such simple acts as brushing off the clothing. If this action does not reduce the radiation levels to twice those given in Graph III or less, then personnel should be advised to change clothing and to bathe.

When the general contamination of a community is of the degree to produce an estimated maximum theoretical infinity gamma dose of 20 roentgens or greater, personnel who have been out-of-doors at any time during the first two days and generally moving around in the area (as apposed to such an act as walking only between a building and a vehicle) should be advised to brush off the footwear (outdoors), to bathe and to change clothing as soon as possible after the final return indoors each day. In addition personnel who go out-of-doors for any length of time during the first two days after such a fallout should be advised to wash their hands at least after the final return indoors each day, and more frequently, if possible.


GRAPH III
GAMMA DOSE RATES VERSUS TIMES AFTER DETONATION
WHEN DECONTAMINATION OF PERSONNEL IS RECOMMENDED
(SEE TEXT FOR METHODS OF MONITORING)
GAMMA DOSE RATE
(MILLIROENTGENS PER HOUR)
TIME AFTER DETONATION (HOURS)
100
10
1

SECTION IV. DECONTAMINATION OF MOTOR VEHICLES

BACKGROUND

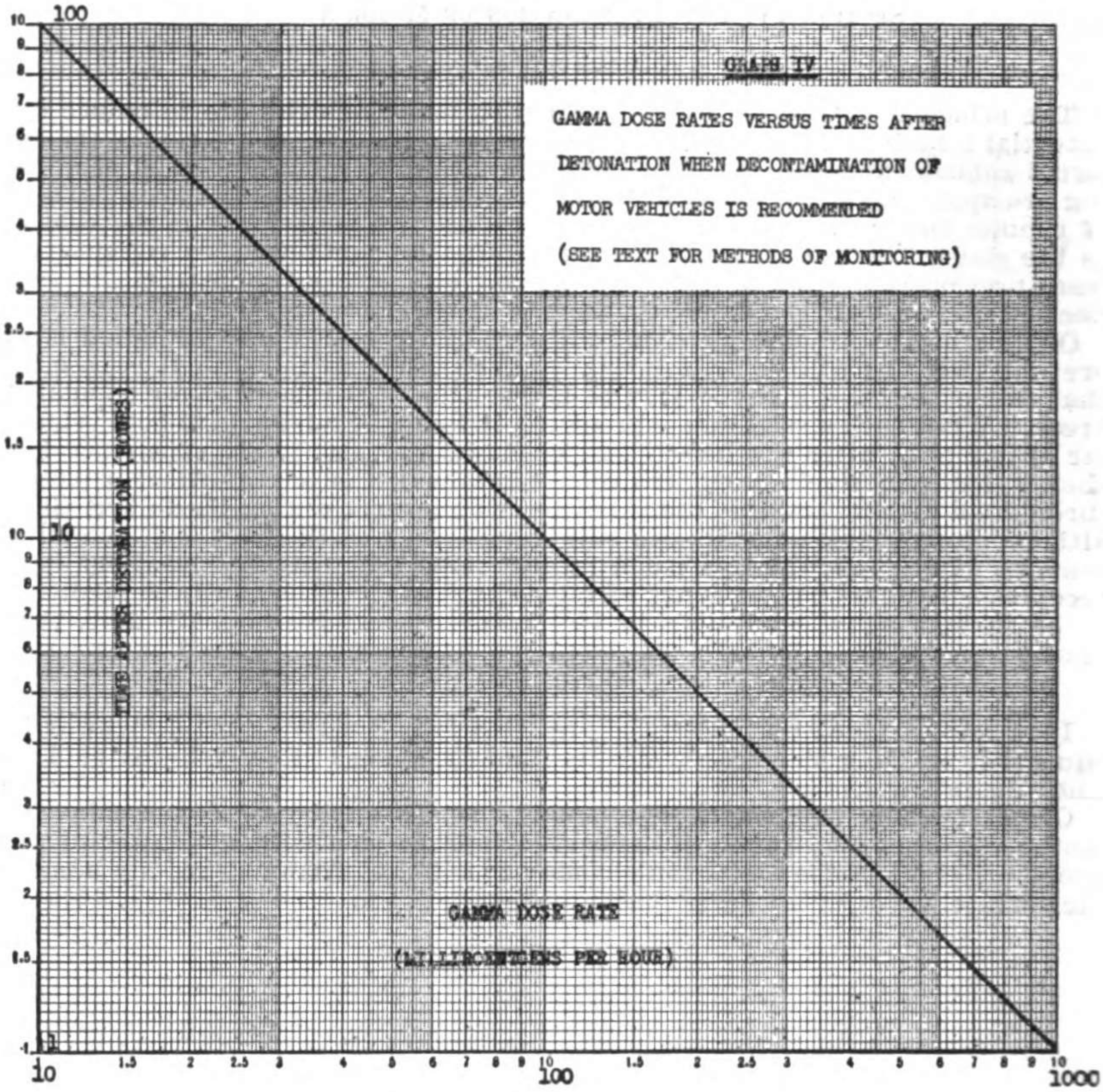
The principal purposes for decontaminating motor vehicles are to reduce the potential beta doses to the skin by contact with the vehicle, and to reduce the external gamma exposure. All of the uncertainties inherent in personnel monitoring are applicable here plus additional ones, such as estimates of the probability of contact and the amount of transfer of radioactive material from the vehicle to the skin. The following criteria for monitoring motor vehicles (Graph IV) were previously developed, and until the new beta measuring instruments (see Section III) are calibrated, will continue to be recommended.

One method of avoiding or significantly reducing vehicle contamination is to prevent their being in an area during the time of actual fallout. It is possible that fallout across a highway may be higher than that permitted for populated areas. When such a condition is predicted, it would be advisable to hold vehicular traffic until after the fallout had essentially ceased. Past experience has shown that very significantly less vehicle contamination occurs when it passes through an area afterwards compared to being present during the fallout time, although appreciable amounts can still be picked up on the tires and under the fenders. Obviously, there is not a precise value that may be given, but it is recommended that if the amount of fallout across a main highway is predicted to be in an amount equivalent to 10 roentgens or greater infinity dose, that traffic be temporarily halted until the fallout has essentially ceased.

CRITERIA IV

It is recommended that when the predicted fallout across a main highway be equivalent to 10 roentgens or greater infinity gamma dose, vehicles be held until the fallout has essentially ceased

Graph IV may be used in determining the advisability of decontaminating motor vehicles. The survey instrument should be held with the center of the probe or center of the ionization chamber four inches from any readily accessible surface.



Section V. Contamination of Water, Air and Foodstuffs

BACKGROUND

In any area where the theoretical gamma infinity dose exceeds 10 roentgens, adequate sampling of the water, air, and foodstuffs should be made to ascertain the conditions of possible contamination, if for no other reasons than as precautionary and documentary measures. Based on past data, however, it is not expected that under those conditions of fallout where the radiation levels are below those stipulated for possible evacuation, that the degree of contamination would be a health hazard. Nor is it implied here that any level above this does constitute a serious contamination of water, air, or foodstuffs. One good point of reference is the Marshallese experience where the whole-body gamma exposure was 175 roentgens yet the internal deposition from ingestion and inhalation was relatively small. In the event of a relatively heavy fallout, but less than one calling for evacuation, a common sense rule would be to wash exposed foods, such as leafy vegetables, since this is the most probable mode of intake of activity.

CRITERIA V

Monitoring of air, fod and water should be made as soon as possible in areas where the infinity dose equals or exceeds 10 roentgens. There need be no restrictive action imposed on food and water intake in areas where the fallout is less than that calling for evacuation. Washing off of such exposed foods as leafy vegetables may be advised when such action seems desirable.

Section VI. Routine Radiation Exposures

BACKGROUND

The Atomic Energy Commission has adopted, as an operational guide, 3.9 roentgens whole body external gamma radiation for off-site exposure resulting from Operation Plumbbob.

The discussion in Section I on effects of weathering and shielding on determining the actual radiation exposure is applicable here. However, the factor of biological repair is not considered for routine exposures. This factor bears on somatic effects and may justifiably be considered in emergency situations when it is necessary to weigh the relative hazards from radiation versus mass evacuation. However, for routine exposures, the actual (estimated) roentgen dose should be used. To distinguish from the Effective Biological Dose and the Infinity Dose, this exposure will be expressed as the Estimated Dose.

Graph V incorporates the assumed effects of weathering and of shielding according to the discussion in Section I. The graph may be linearly extrapolated to other dose-rate readings. For example, if fallout occurs three hours after detonation and the dose rate is 360 milli-roentgens per hour, then about three roentgens (estimated dose) may be accumulated, i. e., $\frac{360}{120} \times 1 = 3$.

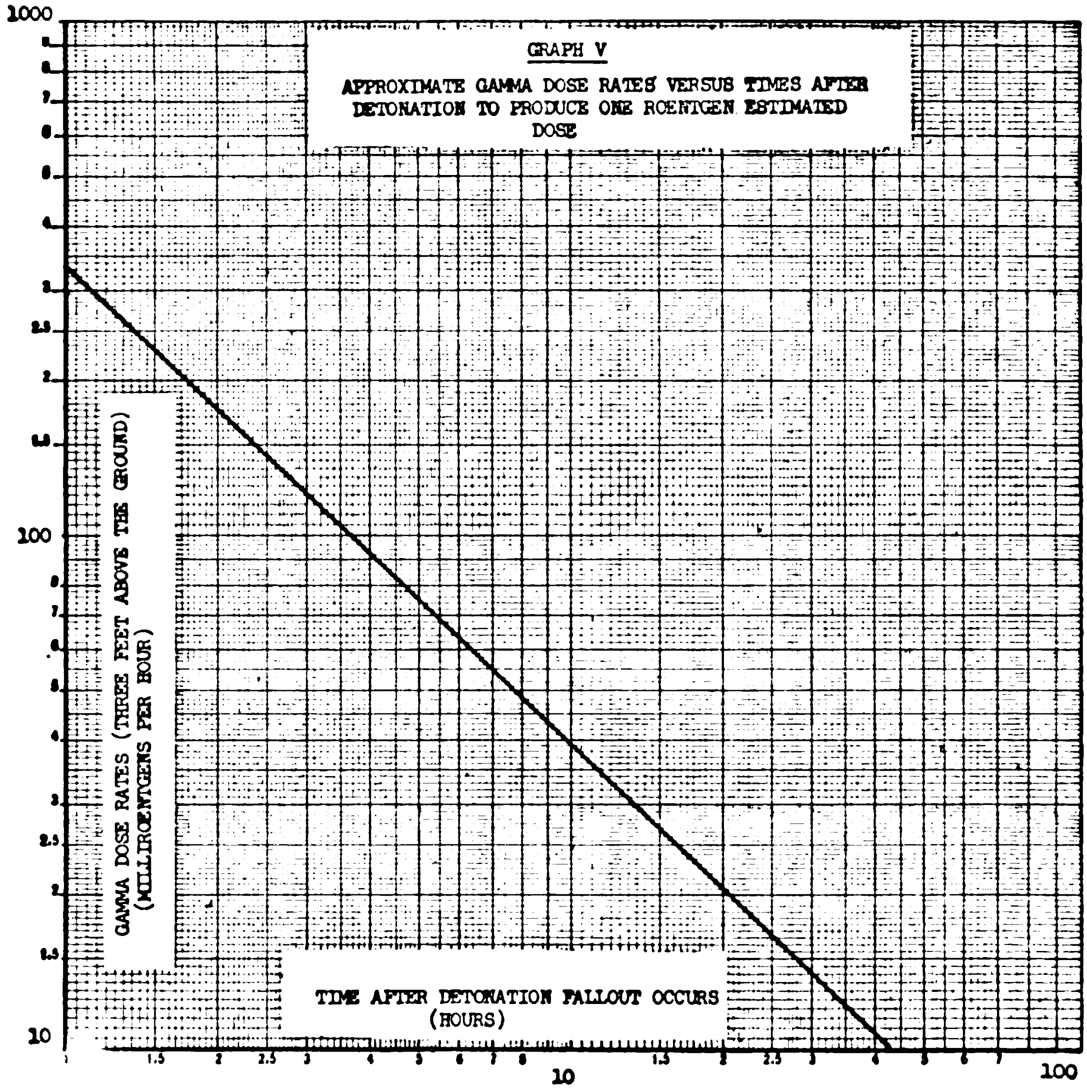
As discussed in Section I, the estimates of the effects of weathering and of shielding may be conservative for areas around the Nevada Test Site. A range of radiation doses is to be expected for these people since they will not all be living under identical conditions. The radation doses estimated by the present method is expected to fall within and toward the upper end of such a range. The information obtained from the expanded radiological monitoring program for Operation Plumbbob, should yield refinements in the method of estimating the radiation exposures.

In those cases where film badges are worn properly by personnel, the values recorded may be accepted as the Estimated Dose.

CRITERIA VI

Estimated Doses may be determined according to Graph V. In those cases where film badges are worn properly by personnel, the values recorded may be accepted as the Estimated Dose.

The whole-body gamma Estimated Dose for off-site populations should not exceed 3.9 roentgens resulting from Operation Plumbbob. This total dose may result from a single exposure or series of exposures.



Representative HOLIFIELD. This afternoon we will have Dr. Forrest Western, Division of Biology and Medicine, Atomic Energy Commission; Dr. Lyle Alexander, Department of Agriculture; and Dr. Roger Revelle, Scripps Institute of Oceanography, as witnesses.

We will meet in the Senate caucus room, room 318, at 2 p. m.

Before we recess, I have several statements to insert in the record at this point. The first is a statement of the United States Naval Radiological Defense Laboratory concerning the prediction, measurement and analysis of fallout and radiological countermeasures. Next a statement by LeRoy H. Clem, of Headquarters, Air Weather Service, United States Air Force. The third is a statement by Col. B. G. Holzman, and Col. Norair M. Lulejian, of the Air Force Research and Development Command, fourth is a statement by Dr. Donald M. Swingle, of the Army Signal Corps, Evans, South Carolina Laboratory, and finally a presentation submitted by James G. Terrill, Jr., Chief, Radiological Health Program, Public Health Service.

STATEMENT OF UNITED STATES NAVAL RADIOLOGICAL DEFENSE LABORATORY

PREDICTION OF FALLOUT

It was realized after the early weapons test operations that there existed a requirement for predicting the then little understood phenomenon of fallout. NRDL made the first studies on this subject by employing scaling techniques (1, 2, 3) similar to the approach used in the determination of blast and thermal

effects for weapons over a wide range of yields. Such scaling of radiological phenomena resulted in satisfactory results when compared to the meager experimentally determined field data (4). As more effects data became available from subsequent weapons test operations (5, 6, 7, 8) the limitations of a straightforward scaling technique were observed and the increasing dependence of the fallout on the dynamical parameters involved, such as the meteorological variables, became apparent. This led to the development of a physical model that would hopefully explain the mechanism of fallout such that given the required input parameters a knowledge of the fallout phenomenology for any type of nuclear detonation could be predicted (2, 9, 10). This model development was initiated by concentrating the effort on surface land detonations. Very little factual data were available for construction of such a model. However, it was realized that this approach offered the most positive chance of success and consequently theoretical assumptions regarding the model input parameters would have to be made. This model then defined the cloud source and associated parameters such as particle size distribution and relation of activity to particle size. A mechanism theory based on the particle settling rates and the effect of the winds aloft in determining the trajectories of these particles was established. A mathematical technique of summing the deposited activity on the earth's surface was developed such that the fallout pattern would then be established.

Because of the many initial assumptions made a great deal of effort was taken in subsequent nuclear weapons test operations to obtain refinements of these parameters by measurement (2). This work included detailed physical, chemical and radiochemical analyses of fallout particles, time dependent studies on the fallout such as time of arrival as a function of distance, rate of arrival, and time to peak activity. Activity levels as a function of distance were made (5, 6, 7). Rockets were employed to establish the radioactivity profiles within the mushroom cloud (11). Such experimental data were employed in the refinement of the physical model as well as were detailed studies of the effect of time and space variation of the winds aloft on the trajectories of the fallout particles. This data greatly improved the ability of the model to predict the fallout and continuing refinements are being made. The use of a physical model for understanding and predicting fallout appears justified (12).

A fallout forecasting technique has been developed to satisfy the immediate needs of the military. This technique employs many of the model parameters established. However it was designed for operational use and predicts only the perimeter of the fallout pattern and the radiological axis of the area or "hot line" (13, 14). It is a rapid system that was tested at Operation Redwing and proved very satisfactory for both surface land and surface water detonations. The details of this technique are described in the enclosed NRDL Technical Reports TR-127 and TR-139.

There has not been developed a satisfactory physical model for underwater or underground detonations to date. For these cases and environmental conditions other than surface or near surface burst the use of scaling techniques holds the most promise. However it is not inconceivable that the mechanism of such detonations will be understood and subsequent models developed.

The accuracy of prediction of fallout is very dependent on the quality of the meteorological data available. With precise meteorological data the area of fallout and direction of the axis of the pattern can be excellently forecast. The quantitative prediction of radiation levels at any point within the fallout area is much more difficult to predict.

It is considered essential in order to insure the application of fallout prediction technique and radiological hazard assessment to a wide variety of detonation conditions that the basic mechanisms responsible for formation of fallout, movement of fallout material in atomic clouds, its dispersal by meteorological forces and return to the earth's surface be thoroughly understood. Only a beginning to develop such an organized set of scientific data has been made.

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Measurement of Fallout

It has been the overall objective of the fallout measurements made by NRDL at the Nevada test site (3, 9, 12) and the Eniwetok Proving Grounds (1, 5, 6), to obtain those data which would allow prediction techniques to be tested and assessment methods developed for the radiological situations resulting from a wide range of nuclear detonation conditions (8).

Since fallout predictions result in the construction of gamma intensity contours, one group of measurements has featured the collection of experimental data for such contours. Direct measurement of the gamma ionization rate at a large number of points in the fallout area with a hand survey meter is the simplest and in many ways the most satisfactory method of obtaining this type of information (2, 4). When the fallout has been deposited on a solid surface, as in Nevada, surveys of this type have generally been used and further supplemented with measurements on instruments calibrated in terms of ionization of the activities of samples collected at certain locations for the primary purpose of physical, chemical, and radiochemical studies. When the fallout has been deposited on a water surface, as in the Pacific, certain other measurements are required for the interpretation of survey results. Because of the way in which the fallout material settles and disperses in the water, it has been necessary to measure its distribution to the total depth of mixing at each point of measurement before the total fallout deposited at that point could be computed. This has been accomplished in part by the use of a radiation sensitive probe which could be lowered to various depths, and in part by measuring the activities of samples collected at various depths. Both procedures have required critical instrument calibrations and theoretical work involving a number of assumptions, however, and it is probable that the results are much less accurate than those for the land surface case. In general, the measurements of this kind made by NRDL have shown that areas of the order of tens of square miles are subjected at early times to ionization intensities greater than 5 r/hr. by events in the low KT range and areas of the order of thousands of square miles to ionization intensities greater than 5 r/hr. by events in the MT range. Levels of several thousand

r/hr. at early times for both yield ranges have been measured or inferred, although less than 10 percent of the total affected area was estimated to have experienced these levels. While the probable error for contours from survey ionization rate measurements has been estimated ±20 percent for Nevada KT events, corresponding land equivalent contours for MT events in the Pacific cannot be estimated closer than within a factor of 2 or 3 at the present time.

Another group of measurements has ben directed toward obtaining time dependent data, such as the variation of the gamma field intensity and gamma energy spectrum with time and the distribution of particle sizes deposited with time at a number of locations in the fallout area (10, 12). Such information is needed both to check model theory which yields similar results and to provide a complete description of fallout phenomena. The changing gama radiation field has usually been measured by means of an instrument which recorded increments of ionization dose received at its location from all sources within unit time intervals, while gamma energy spectra have been measured on fallout samples from a known fallout area with an instrument utilizing a crystal detector, a photomultiplier and a pulse height discriminator (7, 12). NRDL results have shown that the gamma radiation field due to fallout outside the area of severe blast damage tends to build up to a maximum in approximately twice the time required for the fallout to arrive, varying from a few minutes near ground zero to 24 hours or more at distances of over 100 miles. The radioactive decay of fission products may be approximately by a straight line of slope—1.2 on a log log plot; however the more general case in which several induced activities are present, and the fission products are fractionated, leads to a complex decay curve. Spectral measurements show the average energy of the fallout gamma radiations to vary from about 0.6 Mev. at 10 hr. to 0.3 Mev. at 360 hr.

The determination of particle size distributions with time has required the development and application of specialized collectors capable of sampling automatically over consecutive time intervals from a few minutes to an hour or more, as well as special methods and instruments for sizing and counting the collected particles. It has been found that particles with diameters between 100 and 300 microns predominate in most collections with larger sizes (2,000–3,000 microns) increasing nearer ground zero and smaller sizes (20–100 microns) increasing farther away from ground zero. In general, data of this kind, being more direct, are more reliable for computing fraction of the bomb in the total fallout than survey results—although several sources of error such as sample bias 11 and radionuclide fractionation, do exist. On the scale utilized above, standard error in fraction calculations might be estimated at about ±25 percent for the gamma energy and emission rate method, as opposed to possibly several hundred percent by the survey method for water surfaces and less than 100 percent for land surfaces.

Extensive physical, chemical, and radiochemical analyses have been performed on the particulate produced by detonations occurring on the sandy Nevada soil and on coral atolls and the ocean surface in the Pacific. The mass of such material as well as the fraction of the bomb deposited per unit area at a number of locations has also been determined by weighing collected samples and performing radiochemical analyses. Since fallout ingestion constitutes a separate hazard from exposure to external fallout radiation, and since countermeasures and recovery procedures depend heavily on knowledge of the various properties of the contaminant, information of this kind is essential for assessment purposes.

NRDL has consistently emphasized measurements of local fallout and characterization of the phenomena associated with it. It has been possible, nevertheless, to estimate the fraction available for worldwide fallout by subtraction of the local fallout from the total produced, and this has been found to be something of the order of 50 percent for both land surface and water surface events. No closer estimate can be given because of the many uncertainties and sources of possible error in the measurements and calculations.

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Environmental Aerosol Analysis

The United States Naval Radiological Defense Laboratory (USNRDL) collects and analyzes daily aerosol samples for airborne activity of air passing over the laboratory. Twenty-four-hour air samples have been collected and analyzed daily since January 1950, and is a continuing program at the laboratory. The attached graphs present a summary of the long-lived activity and half-life for these daily aerosol samples. Additional analysis on representative aerosol samples indicated this activity is due to airborne beta-gamma fission products. The appropriate dates of the various United States nuclear weapon tests are indicated.

It is observed from the graphs that in 1950 there was essentially no fission product activity in excess of 10^{-14} $\mu c/cc$. In 1951, the aerosol activity rose during the Ranger and Greenhouse operations but then dropped back to an average of 3×10^{-14} $\mu c/cc$. Successive rises and falls of the aerosol activity are noted for the succeeding years. The rises in aerosol activity, fall of 1951, 1953, 1954, 1955, and 1956 were not produced by the United States or United Kingdom nuclear weapon tests. Since December 1955, the aerosol activity has varied between 10^{-13} and 10^{-12} $\mu c/cc$. In other words, the fission product activity background was less than 10^{-14} $\mu c/cc$ in 1950, but is now around 5×10^{-13} $\mu c/cc$. The present concentration of airborne fission products is at most one-tenth of the natural radiactive aerosol (radon and thoron) concentration and is one-fifty thousandth of the industrial maximum permissible concentration for continuous exposure to undetermined mixtures of beta-gamma emitters.

NATURAL RADIOACTIVE AEROSOLS

The earth's surface atmosphere normally contains radioactive aerosols produced by the radioactive decay products of uranium and thorium minerals in the earth's crust. The amount of these natural radioactive aerosols varies from 10^{-14} $\mu c/cc.$ to 10^{-11} $\mu c/cc.$ as determined by the earth's mineral composition in a particular locale. The unit $\mu c/cc.$ (microcuries per cubic centimeter) is a measure of the amount of radioactive material per unit volume suspended in the air. 10^{-9} $\mu c/cc.$ is the present industrial maximum permissible concentration for continuous exposure to undetermined mixtures of beta-gamma emitters.

PROCEDURES

Every air sample contains natural radioactive decay products (mainly radon from the uranium series and thoron from the thorium decay series), and any other radioactive material contamination such as fission products, suspended in the air. In the analysis of the aerosol samples collected at USNRDL, the natural radioactive aerosol products, radon and thoron, are subtracted from the total aerosol activity. The daily aerosol samples are collected at USNRDL by passing 600 cubic meters of air through a 2-inch diameter high efficiency filter paper. The filter paper is then automatically counted for beta-gamma activity with a geiger tube and scaler. The minimum limit of detection on the USNRDL equipment is 10^{-14} $\mu c/cc.$

RADIOLOGICAL COUNTERMEASURES

INTRODUCTION

Most of the USNRDL concepts relative to countermeasures against nuclear attack have been previously presented in the hearings before the Subcommittee of the Committee on Government Operations. One part covering our general concepts appears in part 6 of the hearings on Civil Defense for National Survival held at San Francisco and Los Angeles on May 24, 25, 28, 29, and 31, 1956. These concepts were expanded in those portions involving the emergency periods at hearings held on H. R. 2125 at Washington, D. C., on February 5 and 6, 1957.

GENERAL CONCEPTS

The overall objective of radiological defense is to minimize the effects of nuclear attack on operations. Three time phases of defense actions are apparent: emergency phase; operational recovery phase; final recovery phase. The objectives in each phase are respectively: survival; early recovery of essential functions; ultimate recovery of normal functions. In everyday language, these objectives on a national scale are survive, stay in the war, and win the peace. There is a definite interaction between these objectives: actions which can be taken in any one phase will depend on those taken in other phases.

The general concepts on which the time phases and the respective countermeasures which apply to each phase are discussed in references 1, 2, 6, 8, 9, and 13. Our basic conclusions (reference 9) are that shelter is the central countermeasure in the emergency phase and reclamation is the central countermeasure in the operational recovery phase. The central countermeasure for the final recovery phase will probably be some form of exposure control actions; the precise nature of the actions that will be required have not as yet been taken under investigation by NRDL. In addition, reference 9 discusses other countermeasures that can be used to supplement the central countermeasures; these are called peripheral countermeasures. They include such actions as dispersal, evacuation, operational adjustments to regulate exposure to radiation.

These concepts are applicable to the case of large-scale attack with high yield thermonuclear weapons wherein all persons will be subject to effects of the attack and significantly larger areas will be subject to fallout than any other combination of effects. The concepts also apply to attack with small yield weapons in localized areas where a more limited number of people are subjected to the effects of fallout alone. People in these areas must be prepared to achieve the objectives of the defense system.

COUNTERMEASURE APPLICATIONS

Radiological countermeasures are actions that are designed to reduce, eliminate, or control exposure of personnel to radiation from radioactive material. In the emergency and operational recovery phases, the principal radiological

hazard to personnel is that from external gamma radiation. In the final recovery phase (starting several years after attack), the principal hazard is an internal one from continuous ingestion and/or inhalation of long-lived radioactive materials. Because of the long periods of possible exposure of personnel living in a radioactively contaminated environment, countermeasures must be planned as a phased, long-term, continuous, and coordinated system, Concepts and guides for planning such a system are given in references 1, 2, 8, 12, and 13. The overall system planned for a given installation or locality must be based on an analysis of the vulnerability of the target area to attack and must be independent of the condition of attack.

COUNTERMEASURE COMPONENTS

1. Shelters

The optimum requirement for the shielding afforded by a radiological shelter is a reduction in the radiation intensity of the order of 1,000 to 5,000; the use and requirements for shelters are discussed in references 1, 8, 9, 10, 13, 14, and p21. Reference 14 describes a national shelter system consisting of (*a*) simple radiological shelters, (*b*) radiological shelters with fire-storm protection in areas where fire storms could occur, and (*c*) high-performance shelters in densely populated areas to protect against high blast pressures and fire storms as well as against nuclear radiations. Many existing buildings can serve as adequate shelters; others can serve with some modifications.

2. Reclamation

The basic reclamation techniques presently available and tested are (1) manual decontamination of paved areas, building surfaces, ships, and aircraft; (2) earth-moving procedures on open land areas; and (3) automatic washdown on ships. Most of the data on decontamination are from laboratory experiments on sea-water type fallout, of which only a few of the more recent reports are referenced here. The reports that deal with the general chemistry and physics of decontamination are references 15, 16, 17, 18, 19, p4, p11, p12, and p13. Field-test and engineering-scale data are given in references 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, and p19. The application of these data to countermeasure systems planning is described in references 1 and 8.

In addition to cost of equipment, operating rates, manpower required, and radiation dose incurred, the efficiency of many of the reclamation methods depends on the physical and chemical nature of the fallout. For similar levels of radiation, fallout from detonations at sea consists mainly of sea water residues, and is most difficult to remove from surfaces; fallout from harbor detonations consists of sea water and harbor bottom soils and is more easily removed; and fallout from land detonations consists of contaminated soil particles and is easiest to remove. However, even for the latter case, decontamination of large areas is difficult and time consuming. The relative amounts removed by a method such as firehosing an asphalt road might be in the order of 30, 75, and 95 percent, for sea water harbor and land detonation fallout respectively. The amount of fallout, condition of the surface, and time of removal also influence the results. For this reason, the effectiveness of a washdown system on a ship (at sea) cannot be used as a meaure of effectiveness of a similar system on buildings (on land) without experimental verification.

Peripheral countermeasures in the operational recovery phase include (1) evacuation of nonessential persons to safe areas, (2) readjustment of operation schedules to reduce exposure times, (3) applied shielding such as sandbags around living and working areas. Whereas the presently employed concept in controlling radiation exposure is to exclude personnel from contaminated areas, the only feasible concept in radiological defense is just the reverse: the exclusion of radioactive material from clean areas.

SUMMARY OF STATE OF INFORMATION

The conceptual philosophy of an adequate radiological defense system is, at present, in a more advanced stage of development than are the supporting experimental data required for successful implementation of the system.

The main areas for which experimental data are needed are (1) shelter design and testing (habitability tests, contamination ingress, effects under firestorm conditions, operations in shelter related to outside conditions and future operations, communications problems, and control problems); (2) operational data necessary for testing many of the planning procedures such as those given

in reference 1; (3) reclamation procedures (improve reliability of data on presently available methods, develop and test new, dry, decontamination methods to replace presently recommended methods which require large amounts of water, develop and test of automatic or low-exposure decontamination methods, improve rates and techniques of application of present methods—especially on larger areas, obtain correlations of laboratory and engineering-scale data with data from nuclear tests—most all nuclear tests are not applicable since they are intentionally detonated not to produce fallout of the kind required); (4) definition of the radiological situation and development of countermeasures therefor during the final recovery phase from data on the transport of the radioactive elements in the region of heavy fallout from the radioactive particles into plants and animals used as foodstuffs; such data are required for the planning of necessary countermeasures for a resumption of normal living conditions; and (5) a proof test of a complete proposed countermeasure system under realistic attack conditions (a test in which the complete countermeasure system with all its tested components are put together and in which the countermeasure actions are continued through all the phases); such a test cannot be made under the biased influence of a weapons-development test, since it would take 5 to 10 years to complete, not counting the preparation time.

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A Fallout Plotting Device

RESEARCH AND DEVELOPMENT TECHNICAL REPORT USNRDL–TR–127, NS 081–001, AND UNITED STATES ARMY, NOVEMBER 30, 1956

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ABSTRACT

A fallout plotting device was developed. The method requires no drafting equipment and is ideally suited for field use. At Operation Redwing it was found that untrained personnel could quickly become proficient in its employment.

SUMMARY

The problem

A plotting device is needed to speed up forecasting where fallout will fall in the field. Such a device should require no drafting equipment but still accurately plot the required data in a manner compatible with the latest fallout model theories. It should be so constructed that untrained personnel can quickly become proficient with it.

Findings

Such a device was developed and tested at Operation Redwing. It proved to be satisfactory, and suitable for field operations.

ADMINISTRATIVE INFORMATION

This work was done under Bureau of Ships project No. NS 081–001, subtask 1, technical objective AW–7. The work is described in United States Naval Radiological Defense Laboratory annual progress report to the Bureau of Ships, DD form 613, of July 1956 (enclosure (1) to commanding officer and director, USNRDL Secret letter 3–905–471 EHC: dlc serial 0014921 of August 31, 1956). The plotter was tested at Operation Redwing, project 2.6.3, as described in subtask 4B of NS 088–001 of February 1956.

The work also is part of the technical program for the Department of the Army established between Department of the Army, Office, Chief of Research and Development and Bureau of Ships (joint agreement, Nov. 23, 1955).

INTRODUCTION

This paper describes a rapid technique for plotting "particle-size"[1] and "height" lines in mapping fallout from a nuclear detonation. Since this method,

[1] Particle-size lines are often referred to as hodographs or weighted hodographs.

one of hand computation, uses a fallout plotting device that requires no drafting equipment, it is ideally suited for field use. It was employed successfully at Operation Redwing where it was found that untrained personnel could quickly become proficient in its employment.[3]

The use of particle-size and height lines in mapping fallout is a standard technique employed in most analytical methods now in use. It simply describes a grid (fig. 1) on the earth's surface indicating where certain sizes of fallout particles, originating along a line source through the axis of symmetry of the cloud, will arrive and from what altitude they will come. These parameters are the basic data for describing the fallout pattern.

There are three requirements for determining this grid: the initial distribution of material in the atmosphere; the falling or settling rate of the material from its initial elevation; and the wind field through which the material is falling and by which it is being displaced.

The fallout plotting device computes the points of arrival on the earth's surface of a given particle size that originates at various altitudes within the mushroom cloud and its stem. Particles originating at elevations of every 5,000 feet, from the surface to 120,000 feet, are considered. In the construction of the device, account is taken of the variable speed of the settling particles due to changes in the vertical distribution of the atmosphere's density and viscosity. Aerodynamic falling equations were employed in its design. However, selection of particle falling speeds and altitude increments is arbitrary and not a fixed factor in the basic design of the plotter.

If the average wind speed and direction within a given altitude increment and the time required for a particle to fall through it are known, then the horizontal displacement of the particle can be computed for that altitude layer. Knowledge of the particle's point of arrival on the surface may be deduced from tracing a settling particle as it is displaced by each wind in each altitude increment. Plotting trajectories for each particle size at every starting elevation is the first step in determining the resultant fallout pattern; however, the drafting involved is tedious and time consuming. This effort can be reduced greatly by plotting from the ground up, as is done in the construction of a hodograph. Such a plot is made by starting at ground zero and working up through the altitude increments to the desired elevation. Although this technique does not plot the trajectory of the particle, it does define the arrival points on the surface of the earth of particles starting at each altitude increment (fig. 2).

DESCRIPTION AND USE OF DEVICE

To plot these size-lines one must make the preliminary computations of particle falling times through each altitude increment to obtain the displacement for various wind velocities. The plotter was designed with these computations built in, thereby speeding up the plotting process significantly.

The plotter consists of two parts, a base for direction or azimuth orientation and a wheel for distance or displacement. Since both of its parts are constructed of clear plastic, the plotter does not obscure the map over which it is placed. The base consists of a wind-rose having a radial line at each 10° interval on the compass. The base (fig. 3) has a narrow slot along the 180° line. If a given wind direction (in degrees from which the wind is blowing) is selected and its radial line oriented to north on the map (parallel to the north-south grids), the 180° slot becomes oriented in that direction in which a falling particle will be displaced. Thus by orienting the base of the plotter as described for any measured wind direction, the vector azimuth for the particle can be drawn through the slot of the plotter base.

The wheel (fig. 4) is pivoted at the center of the base. It has 24 equispaced radial slots. Each slot represents an altitude increment of 5,000 feet. Concentric circles intersect the radial slots to form a scale of wind speed in knots. Since the particle falling speed is a function of the atmosphere's density and viscosity and since these factors vary with altitude, the wind speed scales are so weighted

[3] A USNRDL report which will describe the detailed techniques of forecasting used at Operation Redwing and how the employment of the plotter was adapted to consider time variation of the winds is in preparation.

and the indicated length of the scale actually represents the horizontal displacement of the particle through the altitude layer of interest.

To obtain the distance the particle is displaced along its azimuth, the wheel is rotated until the proper altitude layer is alined with the 180° slot in the base and a line is plotted on the map.

It should be remembered that the weighted scales of wind speed fix the map scale, which in this case was 1:970,000 or 1 inch = 13.2 nautical miles. Different wind speed wheels have been constructed for several particle sizes; at present four wheels have been made.[3]

In plotting a size-line with the fallout plotter (fig. 5) one uses the same technique as one does when employing a drafting machine. However, all computations of horizontal displaced distance the particle experiences when falling through a given altitude layer are eliminated.

To plot a size-line or a trajectory, the following steps are necessary:

1. Rotate the wheel until the desired altitude increment coincides with the 180° slot in the base.
2. Place the plotter with the zero value of the wind speed scale over the given point and orient the base so that the radial line, showing the direction from which the wind blows, parallels the north-south grids of the map.
3. Draw a wind speed vector through the coincident slots.
4. Continue the process using the tip of the vector just drawn as the next point.

In constructing the prototype plotters certain specialized parameters were used in making the computations; for example, atmospheric density and viscosity were computed for a Marshall Island atmosphere, particle parameters were typical of coral fallout and special aerodynamic falling speed equations were used. Any of these variables as well as altitude increments may be so selected that a similar plotter for specialized or more general input data becomes possible. Also if one wished to assume a constant falling rate for a given size particle the wheel could be eliminated and the single wind speed scale laid out along the 180-degree slot on the base.

Figures 6A, 6B, 6C, and 7A, 7B, 7C are reproductions of the component parts of the four plotters that have been constructed. These figures can be used to construct a set of plotting devices. A reference scale has been added on each figure to relate the reduced drawings to their original size wherein the scale relationship was 1:970,000.

Approved by:

EUGENE P. COOPER,
Associate Scientific Director.

[3] These wheels are for irregular-shaped particles of density 2.36 g/cc and having diameters of 75, 100, 200, and 350μ. A plotter may be adapted for more than one particle size by adding parallel scales to each radial slot on the wheel.

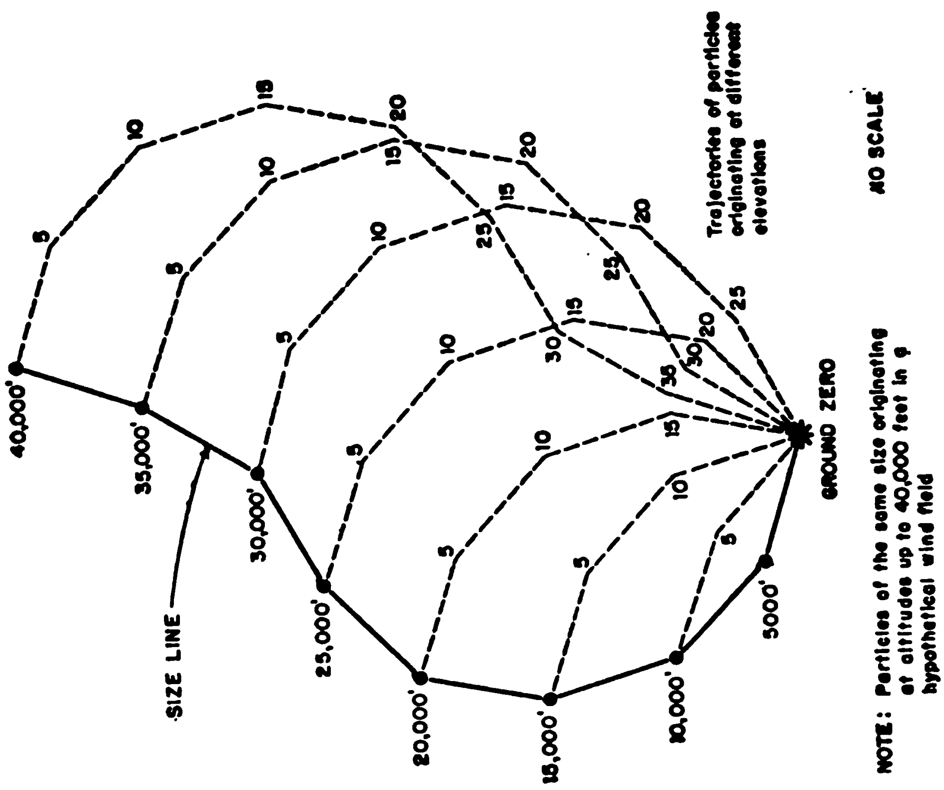

FIGURE 2.—Comparison of plotting techniques either by use of trajectories or by use of a size line.

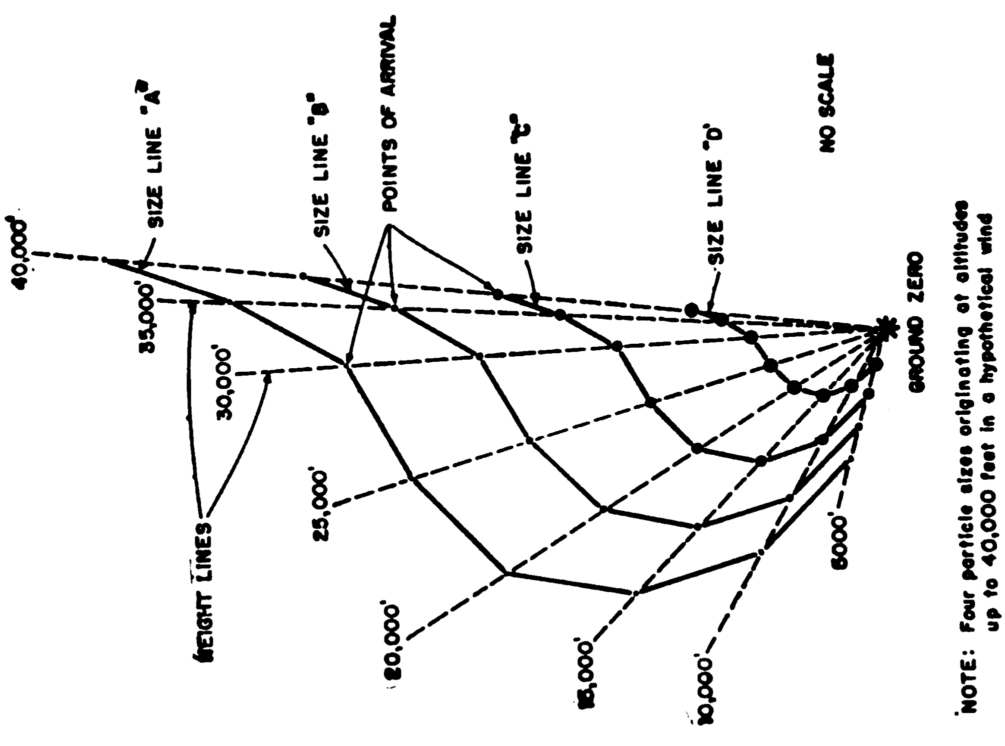

FIGURE 1.—Basic fallout plot showing grid of size lines and height lines.

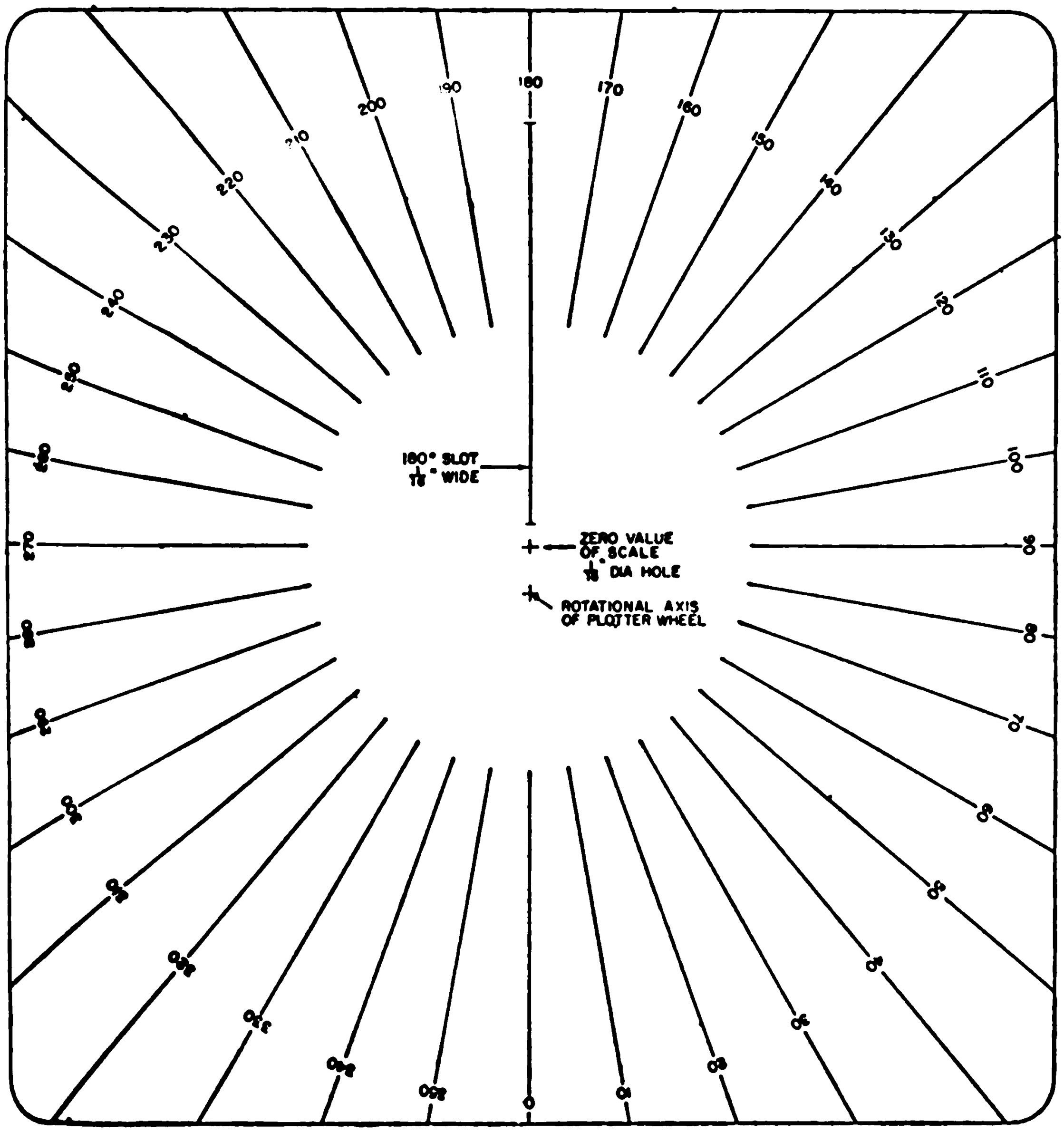

FIGURE 8.—Plotter base, for determining direction.

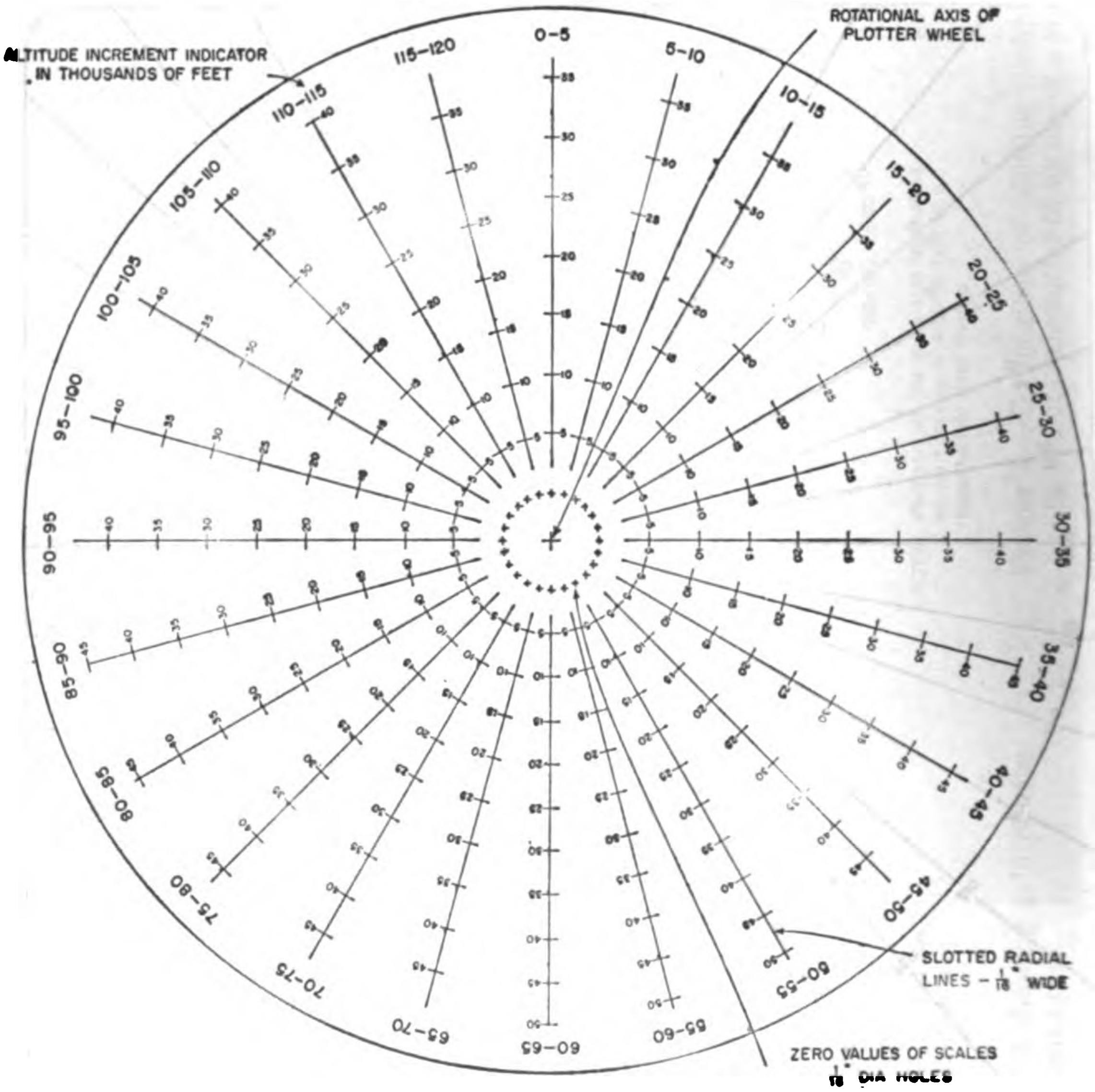

Figure 4.—Plotter wheel for determining displacement of 75-μ particles.

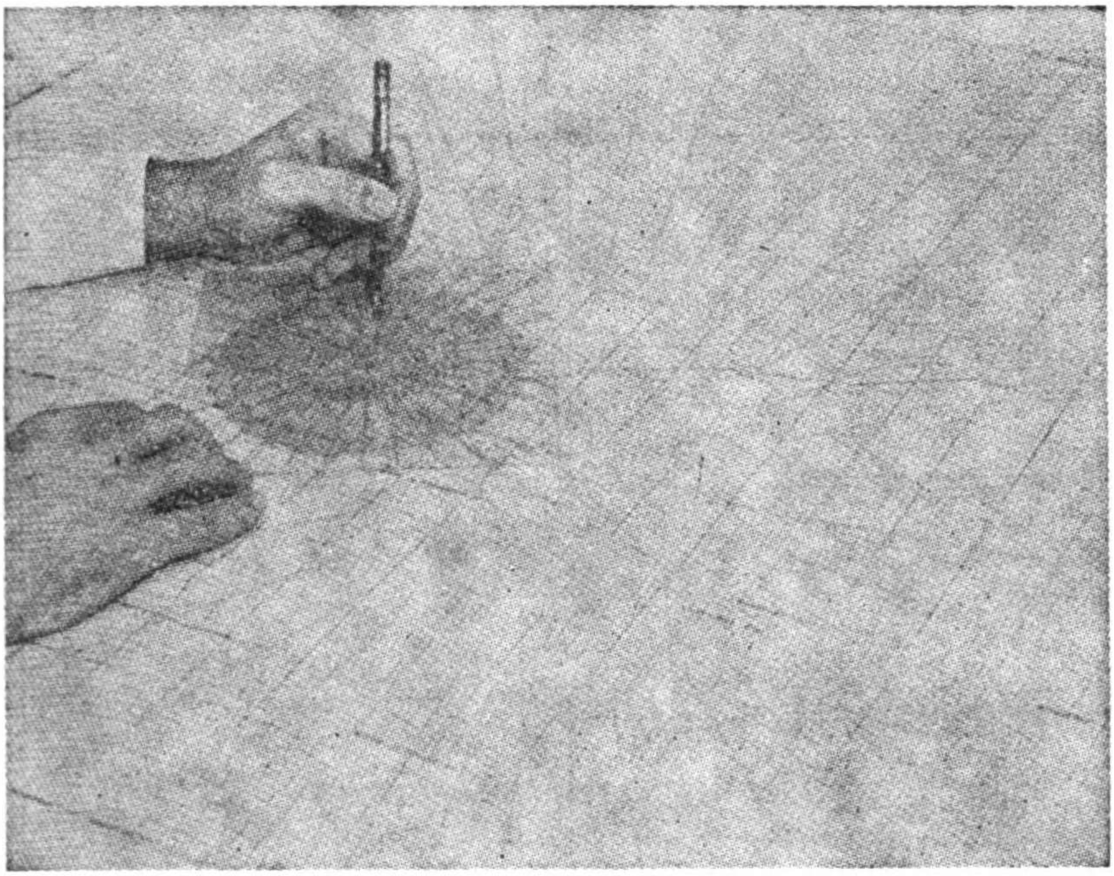

FIGURE 5.—Plotting device being used.

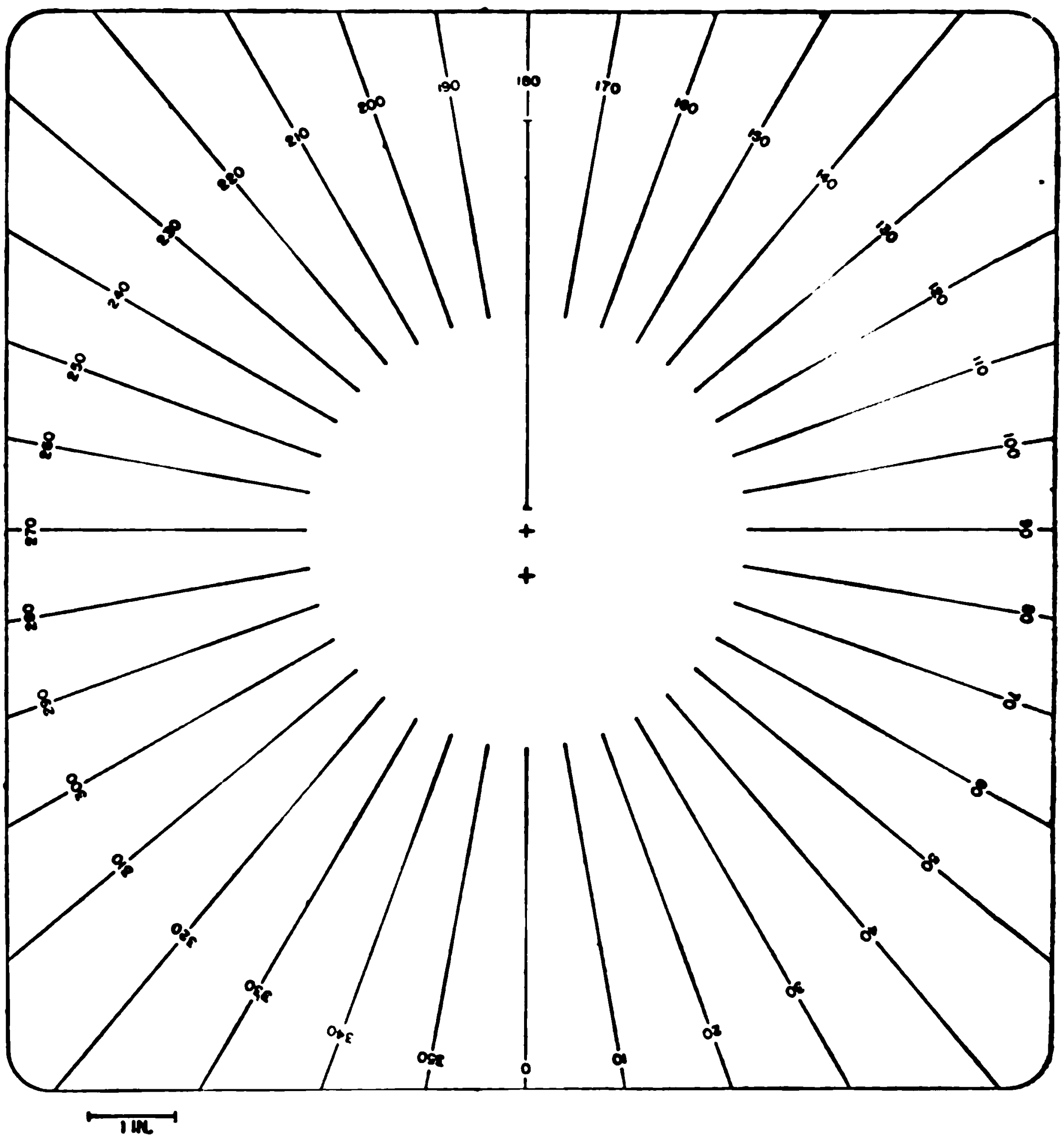

FIGURE 6A.—Plotter base for 75- and 100-μ particles.

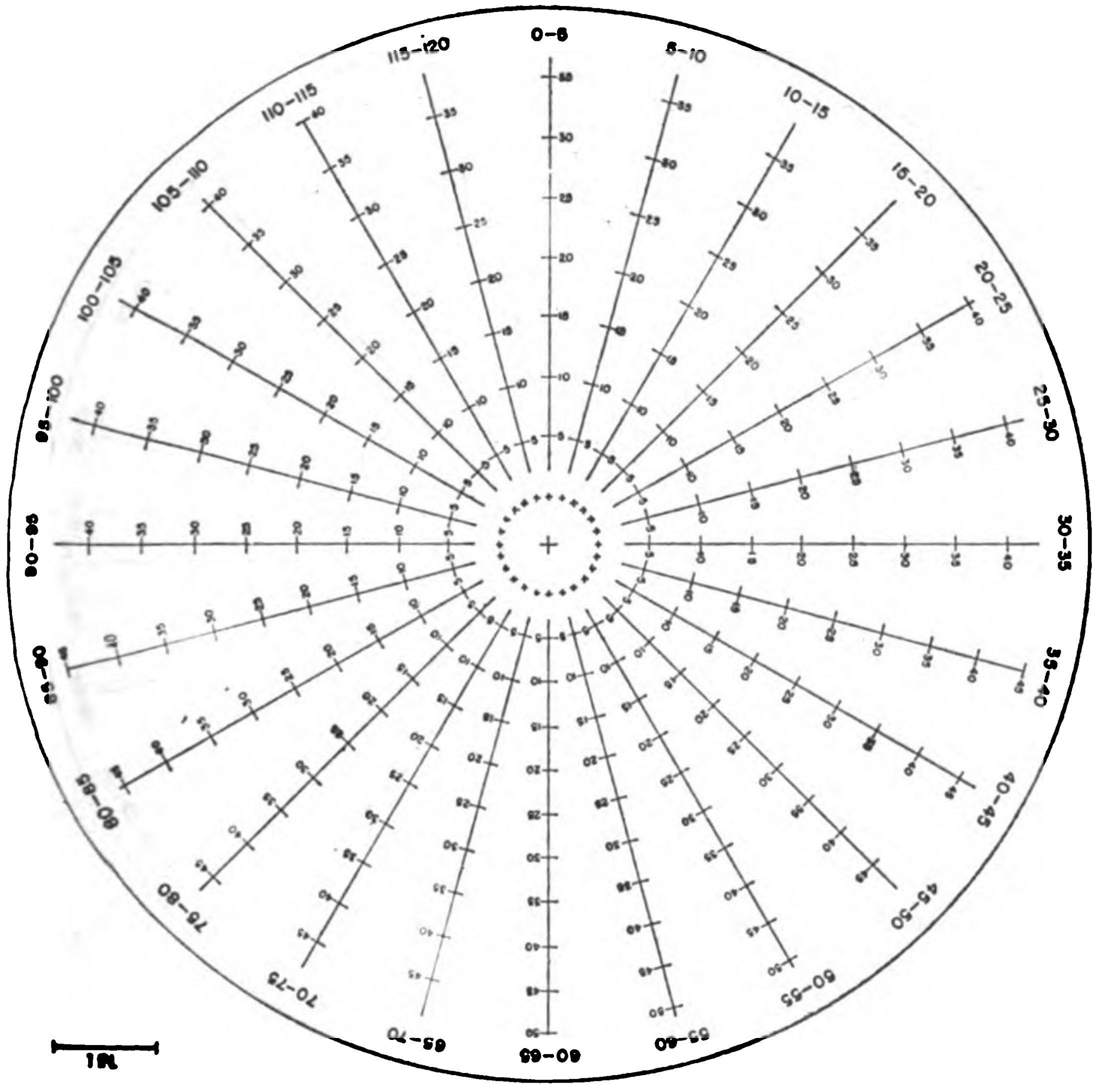

FIGURE 6B.—Plotter wheel for 75-μ particle.

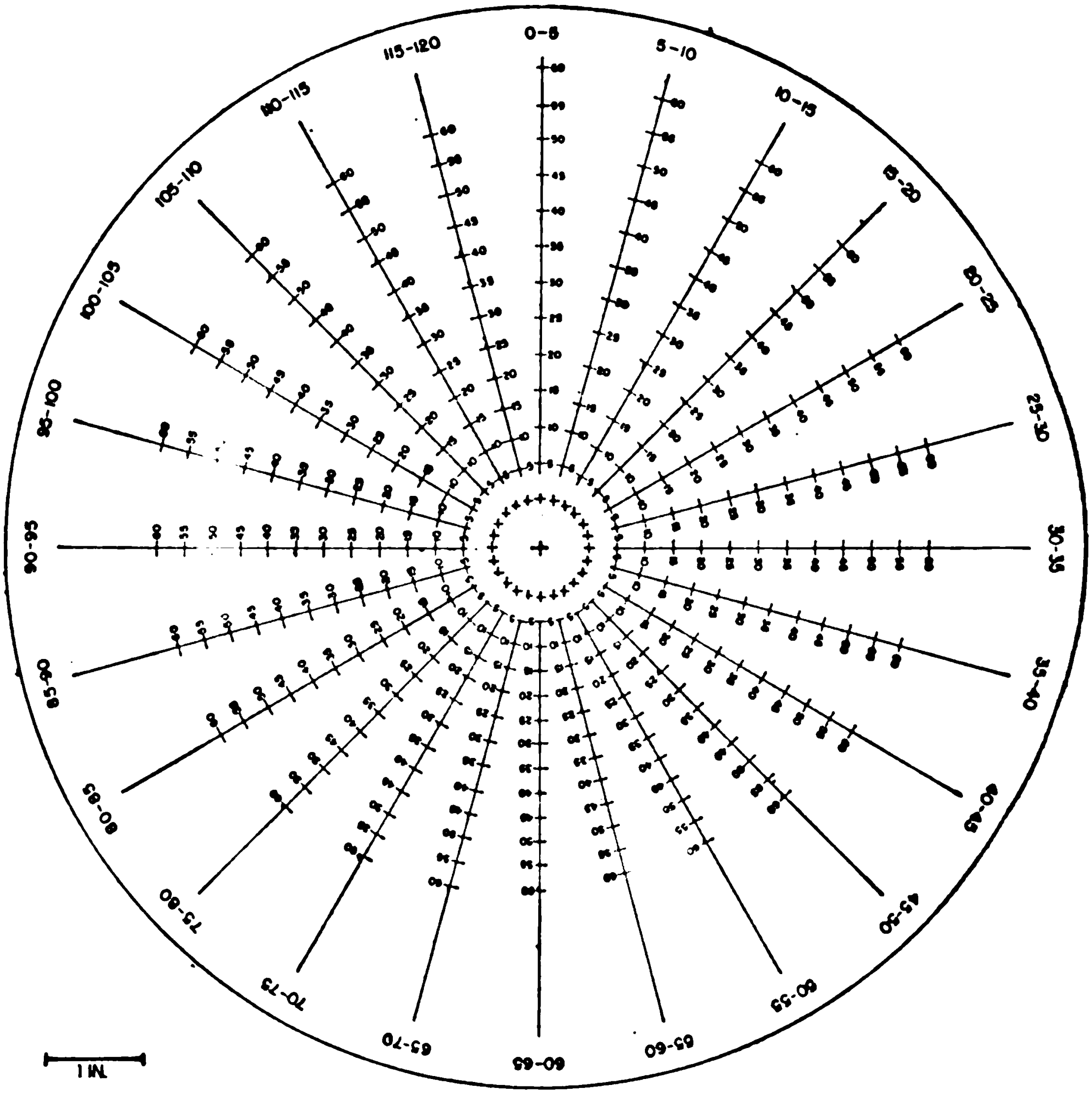

FIGURE 6C.—Plotter wheel for 100-μ particle.

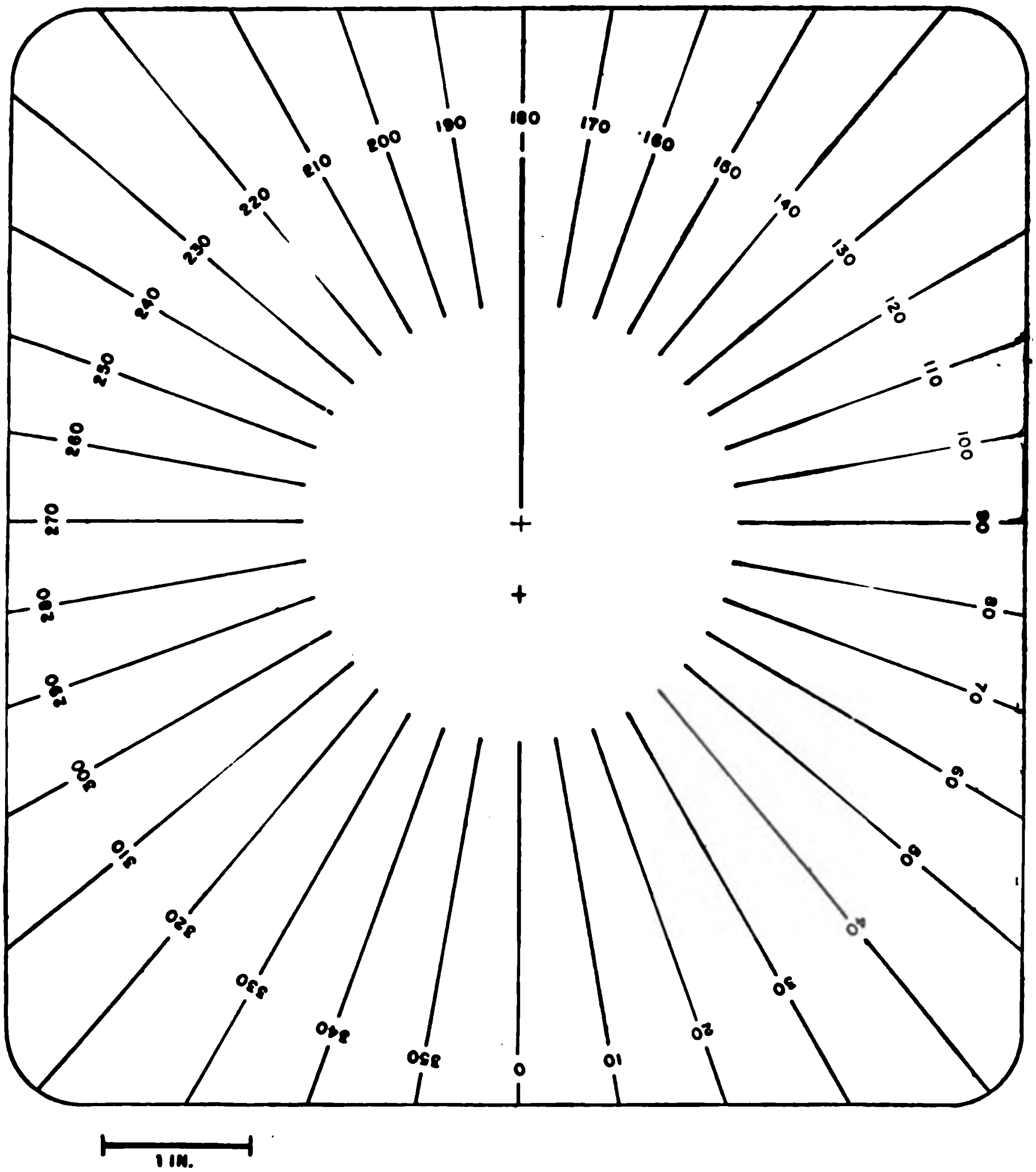

FIGURE 7A.—Plotter base for 200- and 350-μ particles.

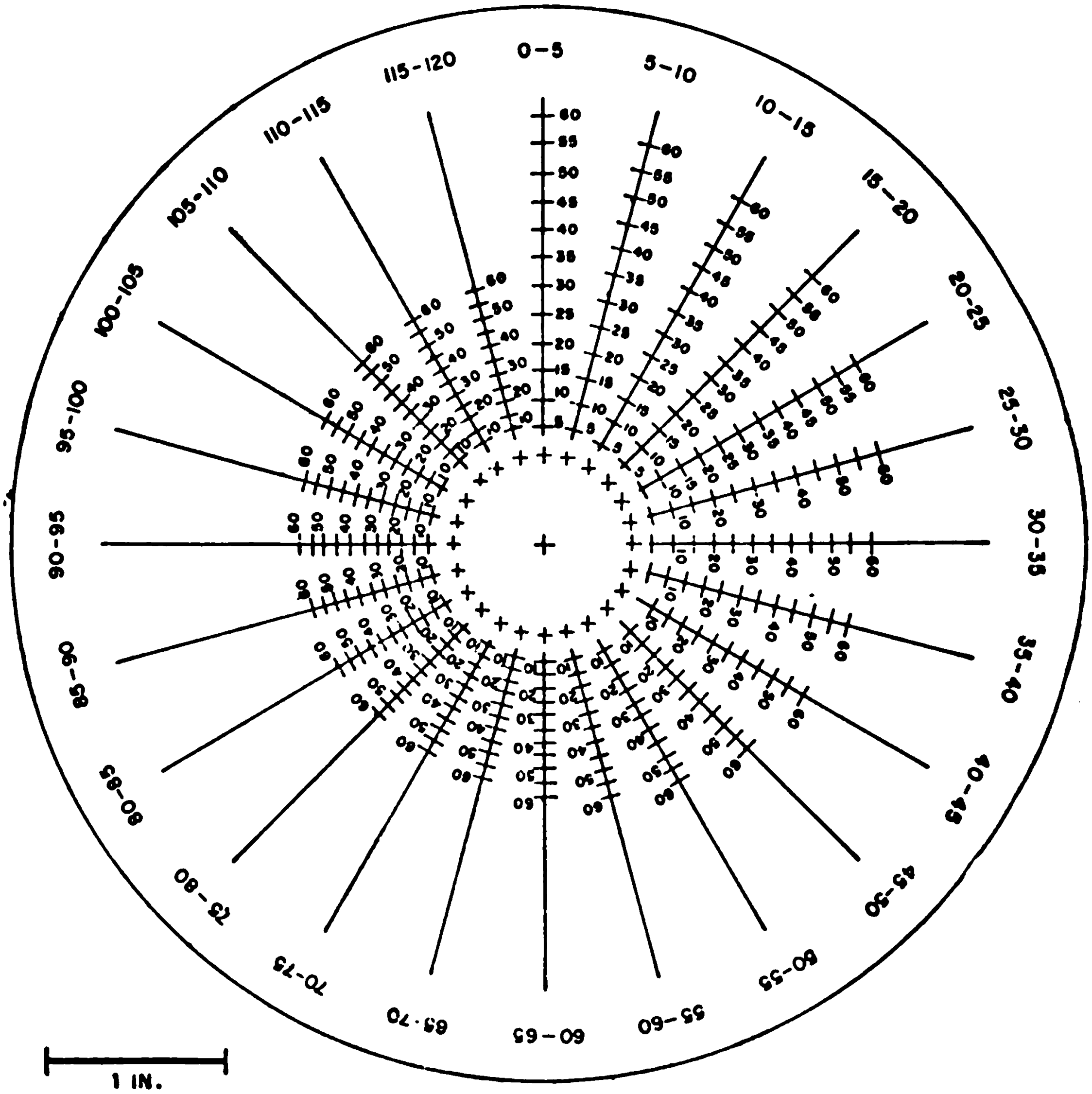

FIGURE 7B.—Plotter wheel for 200-μ particle.

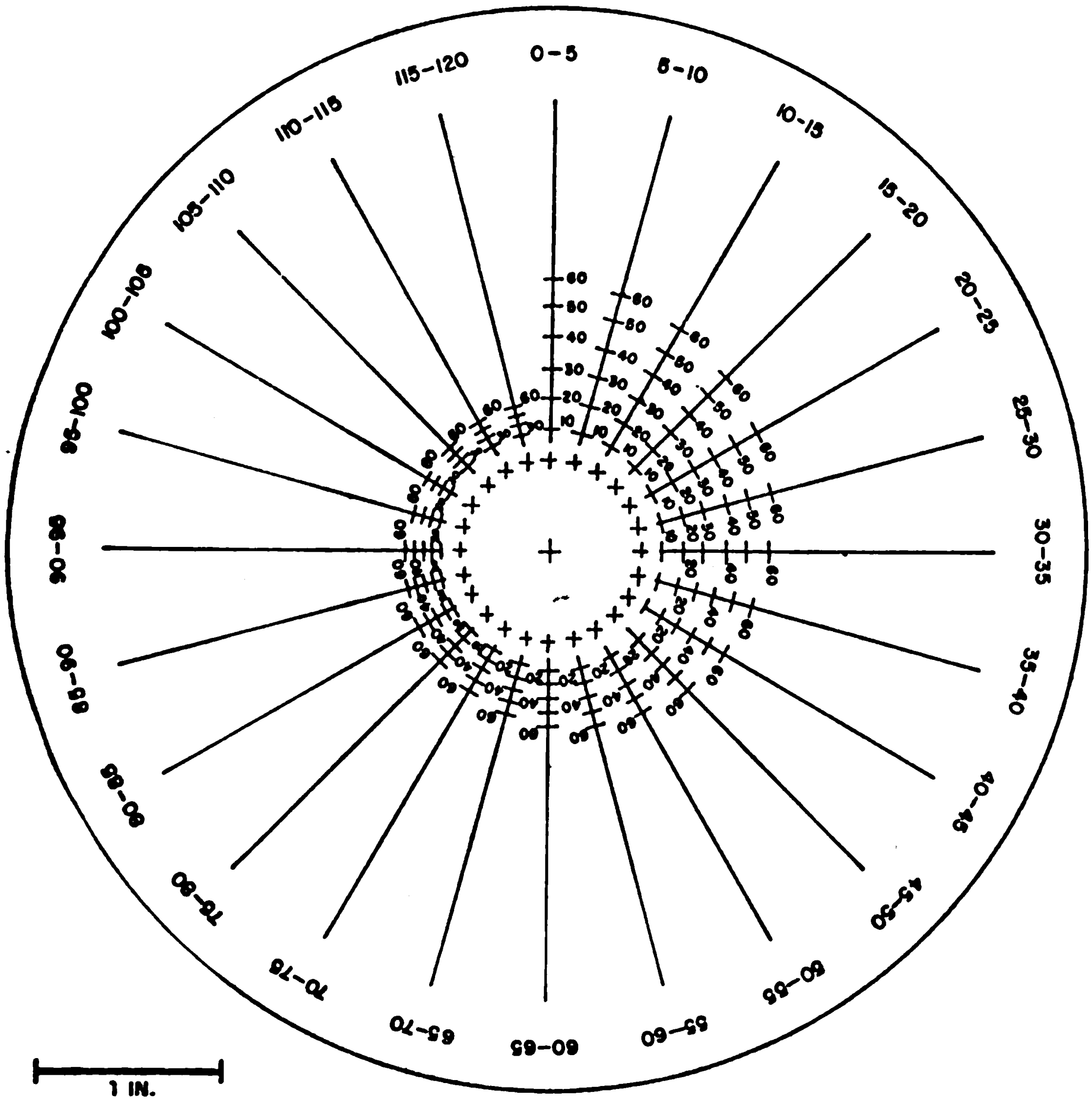

FIGURE 7C.—Plotter wheel for 850-μ particle.

Naval Radiological Defense Laboratory. USNRDL-TR-127. A FALLOUT PLOTTING DEVICE, by E. A. Schuert. 30 Nov. 1956. 19 p. illus. UNCLASSIFIED A fallout plotting device was developed. The method requires no drafting equipment and is ideally suited for field use. At Operation REDWING it was found that untrained personnel could quickly become proficient in its employment.	1. Fallout - Course mapping 2. Plotters I. Schuert, E.A. II. Title. III. NS 081-001. UNCLASSIFIED

A Fallout Forecasting Technique With Results Obtained at the Eniwetok Proving Ground [Draft]

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ADMINISTRATIVE INFORMATION

The work described herein is a part of the research sponsored by BuShips and the United States Army and locally designated as program 2, problem 3, phase 3. Its technical objective is AW-7 and it is described on RDB card NS 081-001.

SUMMARY

The problem: A fallout forecasting technique is needed to qualitatively describe the fallout hazard resulting from nuclear detonations. This technique should have such flexibility that its employment is valid for field use.

Findings: A summary of the latest experimental and theoretical considerations has resulted in the development of a technique whose complexity is dependent on the required accuracy of the results desired. This technique has been satisfactorily tested at the Eniwetok Proving Grounds for land surface and water surface bursts.

ABSTRACT

A generalized fallout forecasting technique is presented with detailed computations of input parameters for use in the Marshal Islands.

Results obtained at a recent weapons test are briefly discussed by comparison of forecast fallout with preliminary measured data.

1. INTRODUCTION

Fallout research continues to seek a theoretical working model that will describe in detail the mechanism of fallout. Aside from this long-range problem, consideration must be given to making available a working tool that will meet the needs of the military for solving fallout problems in the field. Such consideration requires a simplified rapid system capable of producing qualitative if not quantitative results.

Within a program studying fallout at a recent weapons test operation there was a fallout forecasting assignment that had many aspects of the practical

field problem yet, at the same time required quantitative results for use in reducing other data. This program needed positioning data such that three ships could be located properly in the fallout to obtain data on its parameters. Also, aerial and oceanographic survey projects required knowledge of the fallout to instigate their navigational procedures properly.

To meet these requirements a technique for rapid fallout forecasting was developed which not only satisfied the needs of the fallout program but also was accurate enough to allow comparison between meteorological aspects of model work and results obtained from surface measurements. This technique was restricted to describing quantitatively the perimeter of the fallout, the axis of the "hot line," and to determining the time of arrival of fallout throughout the pattern. No attempt was made to quantitate the expected levels of gamma activity or to develop radiation contour lines.

The task force employed a fallout prediction unit at this operation for determining the safe time to detonate the test devices. Many of their techniques for forecasting were similar to those described in this report, however, their problem was of a different nature than that of the fallout program. Several of their methods were unique in that portable analog computers were tested as field instruments. These computers permitted consideration of many complex parameters. One, in particular, obtained essentially an instantaneous solution to the problem once the meteorology was available.

The fallout program and the task force prediction unit functioned independently. It was not feasible for the two to employ the same technique because the postshot variability of the winds aloft were especially critical in ship-location problems in the fallout program. This problem will be discussed in detail later.

1.1 Objective

This report describes a technique of forecasting fallout employed at a recent weapons-test operation. The results obtained in the field are discussed as examples of the reliability of the techniques. Although the technique was designed for analysis ot land surface detonations where the fallout is particulate, its application to water surface detonations is considered.

2. FORECASTING TECHNIQUE

The forecasting technique uses many ideas from fallout model work. Several simplifications as well as a plotting device have been developed to the end that the time involved has been reduced greatly without sacrificing accuracy. In general, an initial source of activity is defined describing the "stabilized" nuclear cloud by appropriate spatial and size distributions of radioactive particles. These particles are tracked to the earth's surface by considering their falling speeds and effects of the winds existing aloft.

2.1 Basic considerations

In some cases the input parameters for the forecasting technique were obtained from weapon-test measurements. In others where data were lacking, the parameters were derived from theory.

2.1.1 Source model

The optical or visible dimensions of the initial cloud from a nuclear detonation have been documented in past weapons tests. Available data describe such parameters as height to base of mushroom, height to top of mushroom, and mushroom diameter all as functions of time. Vertical rise stabilizes in approximately 6 min post detonation. This time is independent of yield, however, the expansion of the mushroom diameter particularly for the megaton devices continues for perhaps 30 min. Available diameter measurements have not been made in excess of H+10 min, however, fairly reliable data are known for the optical cloud dimensions as functions of yield to H+10 min. The ultimate cloud diameter can be extrapolated from low-yield curves and some qualitative data. Figures 1 and 2 present values of the cloud dimensions from past tests. The source model was assumed cylindrical having, for a given yield, these dimensions. Its stem diameter was taken as 10 percent of mushroom diameter.

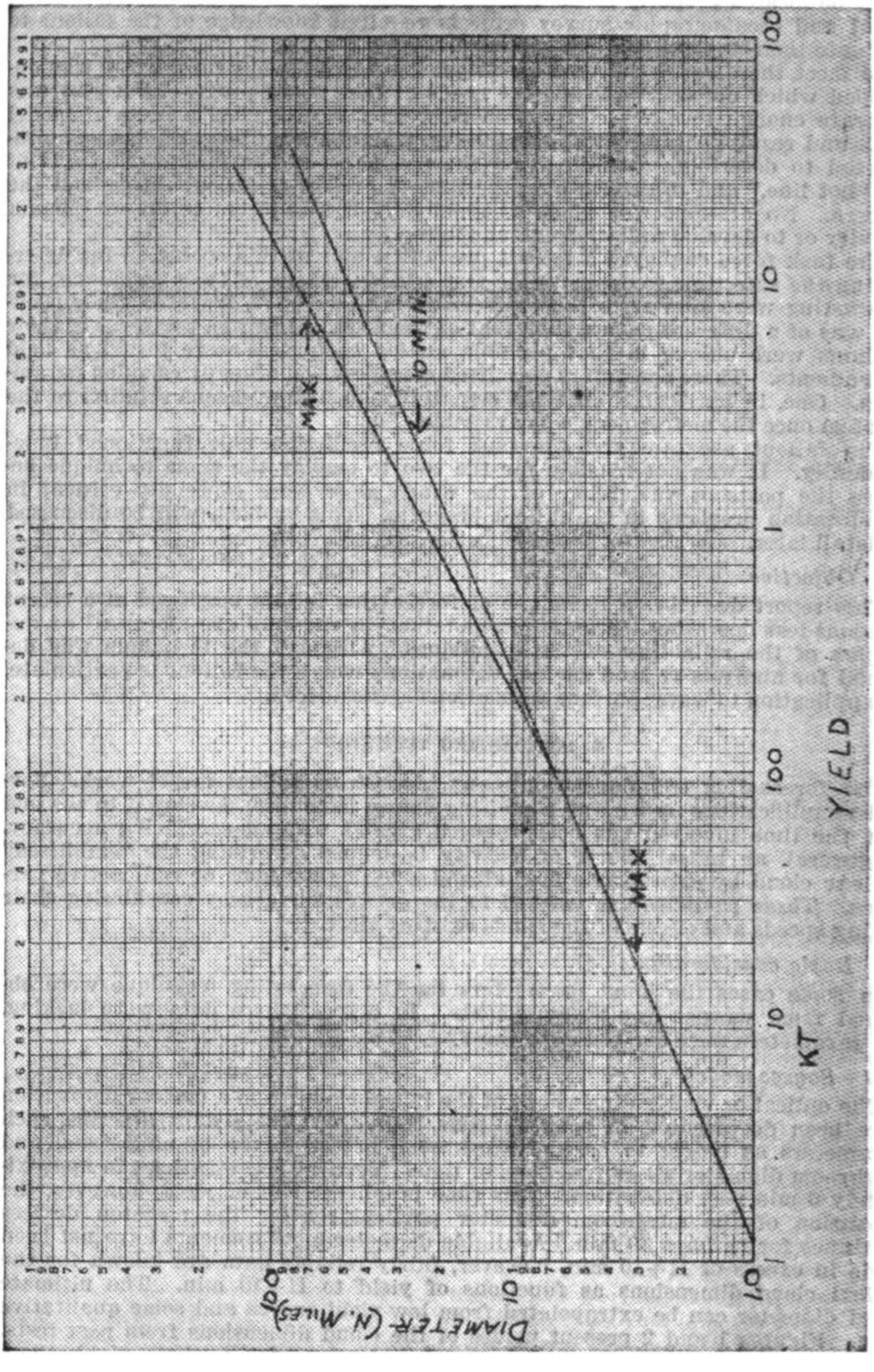

FIGURE 1.—Mushroom diameter as a function of yield.

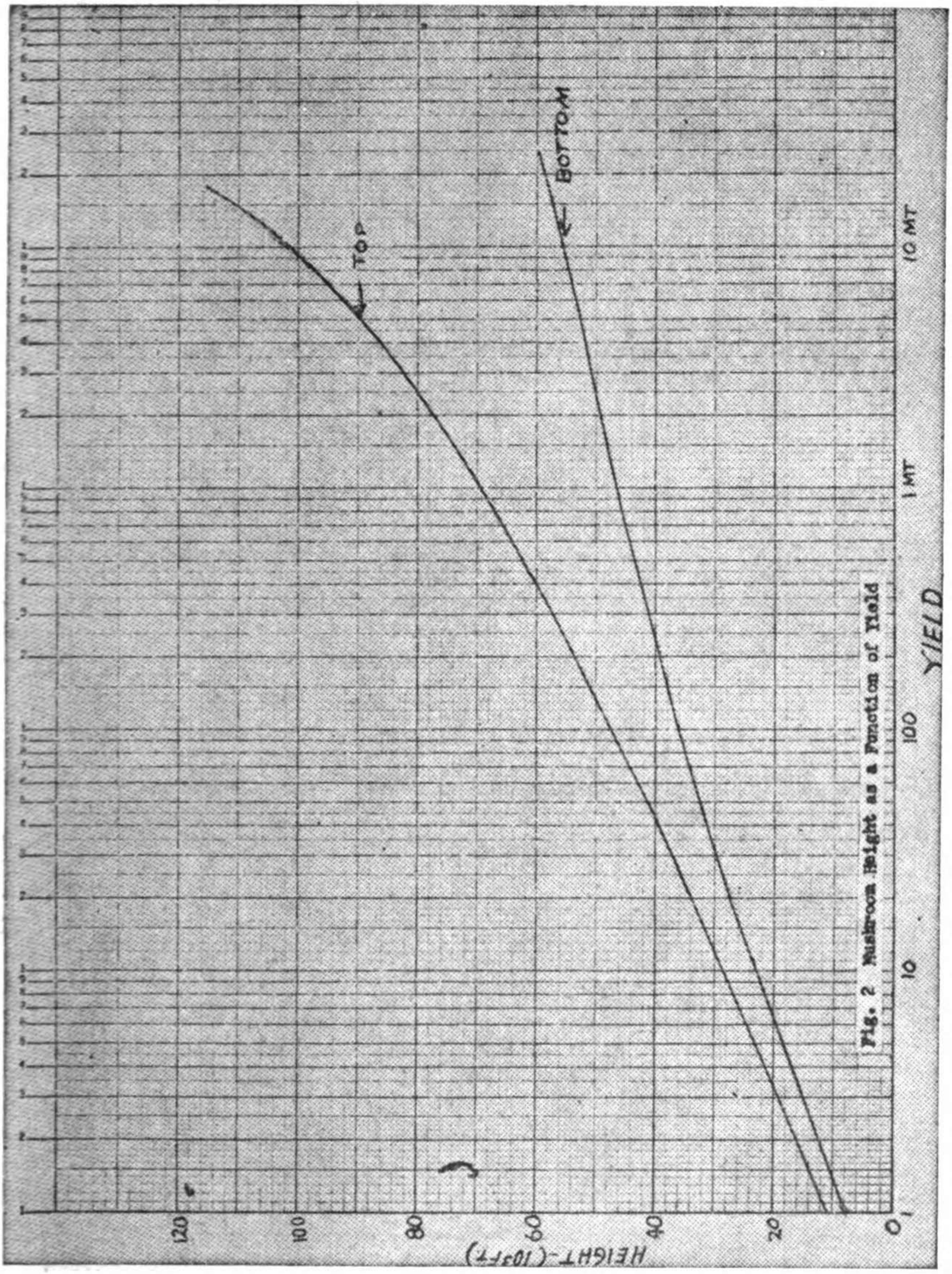

Fig. 2 Mushroom Height as a Function of Yield

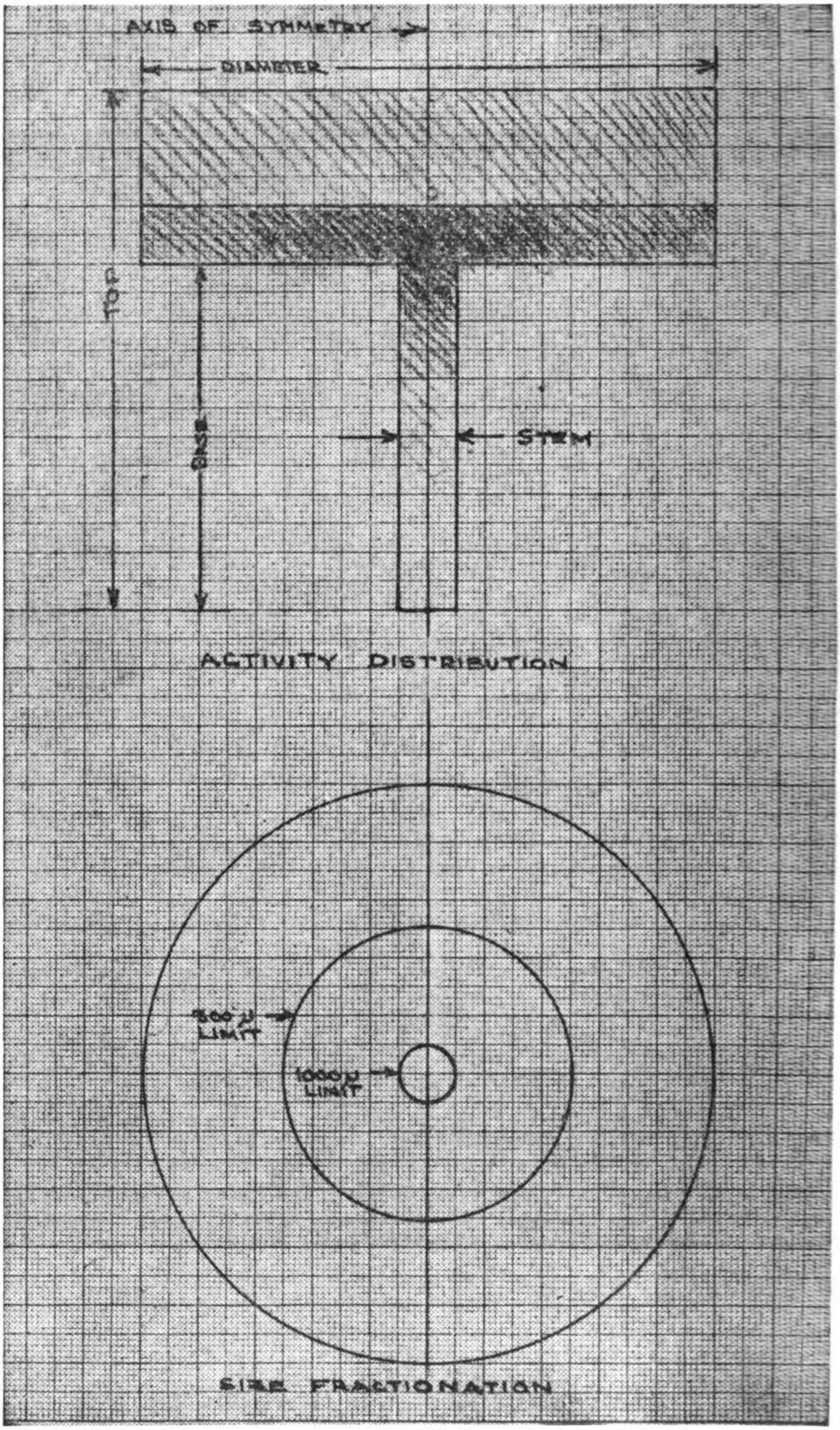

FIGURE 3.—Source model.

2.1.2 Activity distribution in source model

The great part of the activity was assumed to be concentrated in the lower third of the mushroom. The lower two-thirds of the stem was ignored; the remainder of the stem and upper two-thirds of the cloud were weighted lightly. This description (fig. 8) of the activity distribution within the cloud appeared most reasonable in the light of available data and logical theoretical considerations. The activity was concentrated nearer the axis of symmetry of the cloud than at its outer edges.

2.1.3 Particle size distribution in source model

All particle sizes were assumed at all elevations within the cloud except the lower two-thirds of the stem. However, to obtain agreement with past fallout measurements and with the optical diameter of the mushroom, it was necessary to fractionate the particle size distribution radially within the cloud. Otherwise, the computed fallout area about ground zero would be too large. The fractionation was specified as follows: particles of 1,000 microns in diameter and larger were restricted to the inner 10 percent of the mushroom radius or approximately the stem radius; those from 500 to 1,000 microns in diameter were limited to the inner 50 percent of the cloud radius. Since the relation of activity to particle size is some function of the particle diameter this fractionation tends to concentrate the activity about the axis of symmetry of the cloud.

2.1.4 Particle falling speeds or settling rates

Computations of the terminal velocities of the particles were based on aerodynamic considerations for a still atmosphere having temperature and density distributions typical of the Marshall Islands atmosphere in the spring months.

Experimental data from past tests at Eniwetok Atoll indicated that the particles were irregular in shape and had a mean density of 2.36 g/cu cm.

It can be shown that particles falling at their terminal speed experience three types of flow in a fluid: streamline or laminar flow where viscous forces predominate, ($10^{-4} \leq R_e \leq 2.0$); intermediate flow where inertia forces predominate, ($2 \leq R_e \leq 500$); turbulent flow where inertia forces predominate, ($500 \leq R_e \leq 10^5$). Below a Reynolds number of 10^{-4} certain corrections must be applied to the equations because the particle diameter approaches the mean free path of the fluid medium; the region above a Reynolds number of 10^5 is important only in ballistics. These limiting cases will not be discussed here.

The parameters actively affecting a particle's falling speed are: its weight, its drag coefficient, its density, as well as the fluid density and fluid viscosity.

Most empirical equations developed in past experimental work have been for spheres dropped in various liquids. Some work has been done on irregular shaped particles and some done in wind tunnels. The equations[1] used to determine the falling rates for particles in a fluid medium follow.

For Streamline motion, $10^{-4} \leq R_e \leq 2.0$

$$V_s = K_s \left(\frac{\rho - \rho_0}{\rho_0}\right) (d^2) \left(\frac{\mu}{\rho_0}\right)^{-1} \qquad (1)^2$$

where
V_s = terminal velocity in cm/sec
ρ = particle density in gms/cm³
ρ_0 = fluid density in gms/cm³
d = particle diameter in cm
μ = absolute viscosity of fluid in poises
K_s = constant incorporating gravity
= 54.5 for spheres
= 36.0 for irregular shaped particles.

The limiting diameter to which Eq. 1 holds is

$$d' = \left(\frac{36\mu^2}{g\rho_0(\rho - \rho_0)}\right)^{1/3}$$

for spheres and

$$d' = \left(\frac{54.4\mu^2}{g\rho_0(\rho - \rho_0)}\right)^{1/3}$$

for irregular shaped particles.

[1] J. M. Dallavalle, Mircomeritics, Pittman Publishing Corp., 1948.

For Intermediate motion, $2.0 \leqq R_e \leqq 500$

$$V_I = K_I \left(\frac{\rho - \rho_o}{\rho_o}\right)^{2/3} \left(\frac{\mu}{\rho_o}\right)^{-1/3} d_e \qquad (2)^2$$

where $d_e = d - \xi d'$
$\xi = 0.4$ for spheres
$\xi = 0.279$ for irregular shapes
d' = limiting diameter to which streamline motion applies
$K_I = 30.0$ for spheres
$= 19.0$ for irregular shapes.

The limiting diameter to which the Eq. 2 holds is

$$d'' = 43.5 \left(\frac{\mu^2}{g\rho_o(\rho - \rho_o)}\right)^{1/3}$$

for spheres

$$d'' = 51 \left(\frac{\mu^2}{g\rho_o(\rho - \rho_o)}\right)^{1/3}$$

for irregular shapes.

For Turbulent motion, $500 \leqq R_e \leqq 10^5$

$$V_T = K_T \left[\left(\frac{\rho - \rho_o}{\rho_o}\right) d\right]^{1/2} \qquad (3)^2$$

$K_T = 54.6$ for spheres
$= 50.0$ for irregular particles.

The question of particle diameter becomes puzzling when the equations are applied to irregular shaped particles. Although the equations for irregular shaped particles cannot be applied to an individual particle, they are assumed valid in establishing the average falling rates of many irregular particles clustered about this defined size.

2.1.5 Marshall Islands atmosphere

Marshall Islands atmospheric conditions determined the values for the density and viscosity parameters used in computing particle falling rates. Available data on the temperature, pressure, density, and viscosity as functions of altitude for the atmosphere common to the Marshall Island area in the spring months follow.

It was not possible to use a "standard atmosphere" in this problem because such use introduced a large error in the particle falling rate at high altitudes. This error originates primarily because of the assumed isothermal layer above the tropopause.

2.1.5.1 Temperature distribution

From the weather data published by Task Force Weather Central at Operation Castle, four published radiosonde runs obtained temperature measurements to high altitudes:

March 1, 1954, 0600 M Bikini
March 27, 1954, 0600 M Bikini
April 7, 1954, 0620 M Bikini
April 26, 1954, 0610 M Bikini

No data were available above 67,000 feet. Fortunately two of these runs penetrated the tropopause which was located at approximately 55,000 feet. To extend the measured data beyond 67,000 feet climatological averages [3] for latitude 12° North were employed. Agreement with measured data was satisfactory except for the range from 50,000 to 65,000 feet where the climatological data indicated a well-defined isothermal layer. The most significant finding from the measured data was the complete lack of an isothermal layer above the tropopause. Instead, a distinct and rapid inversion was observed which when extrapolated as a straight line agreed with the climatological data above 70,000 feet. Since the atmosphere was to be defined to 120,000 feet further extrapolation was necessary. The only temperature data available at these higher altitudes were taken by rockets [4] over White Sands, N. Mex. A plot of 3 points from the rocket data justifies to some extent a continued extrapolation of the curve to 120,000 feet.

[2] These equations were taken from reference 1; however, certain constants have been reevaluated.
[3] Brunt, David, Physical and Dynamical Meteorology, the University Press, 1941.
[4] Chief of Naval Operations, A Study of the Atmosphere Between 80,000 and 100,000 Feet (preliminary report), September 1948.

Therefore the profile of the vertical temperature gradient (fig. 4) was based on measured data to 67,000 feet and extrapolated to 120,000 feet on the basis of supporting climatogical data and temperature measurements made at high altitudes with rockets.

2.1.5.2 *Pressure distribution*

Published high altitude measurements of the pressure distribution were obtained on two occasions at Operation Castle. These measurements [6] were made at Bikini on April 7 and 26, 1954, and were not taken above 65,000 feet. Above this altitude the pressure was extrapolated as a straight line on semilog paper to 120,000 feet. Agreement with published rocket data from White Sands, N. Mex., was good to 90,000 feet (fig. 5).

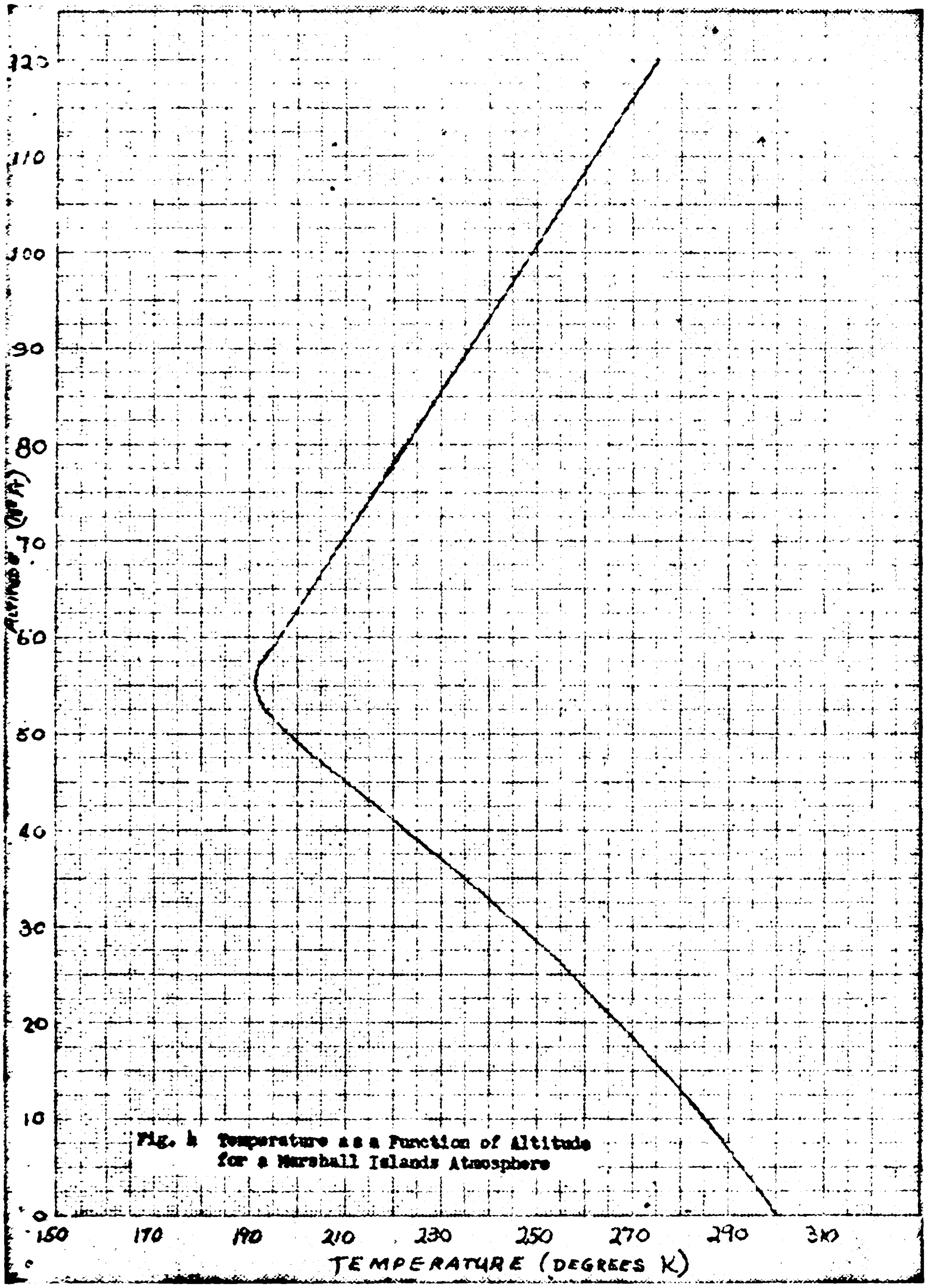

Fig. 4 Temperature as a Function of Altitude for a Marshall Islands Atmosphere

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[6] Hq. T. U.-13 operation memo No. 14, April 3, 1954.

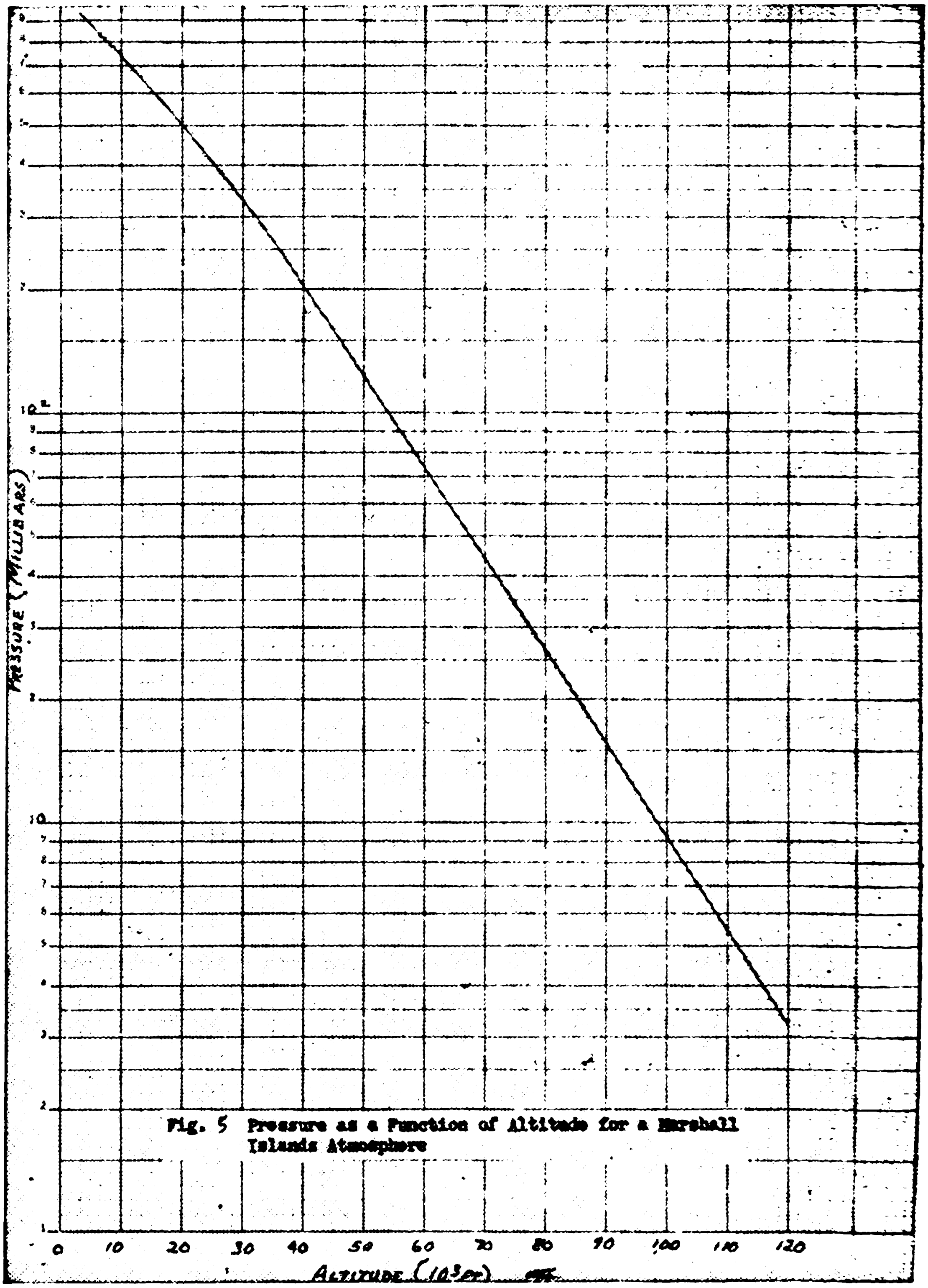


Fig. 5 Pressure as a Function of Altitude for a Marshall Islands Atmosphere

2.1.5.3 Density distribution

The density distribution of the atmosphere (fig. 6) was calculated from the perfect gas law using the above pressure and temperature distributions,

$$\rho = \frac{P}{RT}$$

where the gas constant was taken for dry air. This assumption of no moisture in the mixture introduces an error of several percent in the lower layers of the atmosphere where the relative humidity is high; however, it can be safely neglected. As well, the latest theories on the composition of the atmosphere indicate it to be constant to altitudes above 150,000 feet which justified the assumption of a non-varying gas constant.

PHYSICAL CHEMISTRY OF FALLOUT AS IT RELATES TO DECONTAMINATION COUNTERMEASURES

GENERAL BACKGROUND

In countermeasures, the basic physical chemistry of fallout is concerned with the interactions of fallout with surfaces. These interactions are then related, in a practical sense, to an appropriate choice of reclamation procedures. Further, an understanding of the chemistry leads to a precise concept of the nature of fallout and to the significant properties of both the weapon and the target that combine to produce fallout of a given chemical nature as well as the implication of these properties on the countermeasure performance.

In radiological defense designed for nuclear attack there are three basic kinds of fallout of interest: (1) From detonations at sea, (2) from detonations on land, and (3) from detonations on harbor targets. The general description of the interactions of these kinds of fallout will aid in explaining some of the technical problems; some of the experimental data and techniques are also applicable to reclamation problems which might range from a laboratory spill of a small amount of activity to a reactor accident although none of these would ever approach the scope of the reclamation task envisioned in event of fallout from nuclear attack.

SEAWATER FALLOUT

Seawater fallout will consist of seawater, bomb structural and target materials, and radioactive products. The bulk of the material thrown up in a detonation at sea will be seawater of which about 3 percent of the weight is salt (mainly sodium chloride); the radioactive elements will be present at concentrations less than 1 part in a million. A high yield explosion will throw this material to such altitudes that much of the water can evaporate in falling back to earth; with lower yield explosions less will evporate. Depending on the humidity, in one extreme the fallout might arrive as wet, saturated salt particles and in the other as water droplets much like rain.

When these droplets or pseudo crystalline salt particles strike a surface (for simplicity, assume an impervious surface such as painted metal or wood) they will tend to stick where they land, and since fine mistlike particles travel almost horizontally more of them can strike and stick on vertical surfaces. Larger water droplets, however, when deposited in large numbers will fall more vertically and run off vertical surfaces.

Since the bulk material (salt) is water soluble and never completely dries out (or stays dried out) in the presence of water vapor in the atmosphere, the radioactive as well as the salt atoms (ions and colloids) can move about in water and diffuse toward the surface. Within several hours after deposition, the droplets will all evaporate to the same degree under the same conditions and reach the same equilibrium state with respect to the surface.

In this environment each radioactive atom has some freedom of movement and each kind (element) will interact with the surface in its own characteristic manner. The major interaction with the surface in this case is adsorption of individual elements (especially the metallic elements). The alkali elements (like sodium or cesium) do not adsorb on surfaces very strongly, the alkaline earth elements adsorb in larger extent, and the rare earth elements to a greater extent than the alkaline earths. The degree of adsorption is in order of the charge on the ions from +1, +2, to +3. The equilibrium amount of each adsorbed depends on the amount of each present initially in the drop. The amount directly adsorbed by the surface cannot be removed without either removing some of the surface, or without imparting a great deal of energy to the surface layer either by physical or chemical means. Water washing, for example, simply washes away the equilibrium amount left in the salt layers above the surface.

The Freundlich adsorption isotherm can be adapted to describe the adsorption process and subsequent washing of the surface. For a given element, it is—

$$F_j = R_j/I = a_j I^{n_j - 1} \qquad (1)$$

in which I is the initial level (later defined in total r/hr of which element j contributes a stated fraction at the time, t, after detonation; R_j is the amount left after washing (i. e., the amount adsorbed); and a_j and n_j are the impirical adsorption constants. The fraction remaining is—

$$R_j = a_j I^{n_j} \qquad (2)$$

equations (1) and (2) apply either to a single drop or to the whole surface if at least a single layer of drops has been deposited. The intermediate situation is for rather low contamination levels and requires rather complicated equations; therefore, the following treatment will assume a serious contamination of the surface as the lower initial level of interest. For chemisorption which obeys equation 2, n_f is less than 1 so that the fraction remaining decreases with decreasing initial level.

In this type of fallout, another interaction can take place within the water drop either during its fall to earth or after it lands. Likely bomb and target structural materials will include fairly large amounts of iron, aluminum, etc. These materials will be oxidized and will form hydrous precipitates in the water drops. Many of the radioactive atoms will adsorb or mix with these precipitates. When these are present, a three-way interaction occurs on the surface rather than just the one previously described. Simple washing methods will dissolve only a small amount of the precipitates once they are dried on the surface, and during the process an equivalent amount of the radioactive elements will be released.

A rigorous mathematical solution of all the physical chemistry equations and material balance equation for the three-way process cannot be made; however, suitable approximations can be made for simple water washing of the surface. The fraction remaining for this case is—

$$F_i = a_i I^r j + \frac{I}{k_i + I} \tag{3}$$

in which, for a given element,

$$K_i = dK_c V / q_r(t) \tag{4}$$

in which (1) d is the density of the hydrous oxides.
(2) V is the equivalent initial volume of the fallout (before evaporation begins), deposited per unit area of surface.
(3) K_c is the equilibrium constant for the distribution of the element between the liquid and solid phase,
and (4) $q_r(t)$ is the ratio of the weight of the bomb (and target, as Al, Fe, etc.) per unit area to the amount of radioactive elements present; $q_r(t)$ therefore depends on the yield and is given by

$$q_r(t) = \frac{kM_B Y(t)}{bW[A_{FP}(t) + a_I(t)]} \tag{5}$$

in which (1) M_B is the total mass of bomb (and target material thrown up),
(2) $Y(t)$ is the ratio of r/hr to d/m per unit area at time, t, after detonation and depends on the photon energy spectrum,
(3) W is the total yield of the weapon,
(4) b is the ratio of fission to total yield,
(5) $a_{FP}(t)$ is the activity of the FP from 10^6 fissions in d/m at time, t.
(6) $A_I(t)$ is the sum of the induced activities for 10^6 fisisons in d/m at time t.
and (7) K is a constant relating the fission yield and the number of fissions in appropriate units.

The various quantities illustrate the kind of weapon or detonation parameters which are related to the chemical interaction at a surface many miles away from the attack as well as the information required to properly interpret decontamination test experimental results.

LAND FALLOUT

Land fallout will consist of soil material, bomb structural and target materials, and radioactive products. The bulk of the fallout material from a surface detonation will be soil particles in which the radioactive elements are fixed. Therefore a decontamination procedure which moves the particles from a surface also moves the radioactive material.

In this case, the fallout particles maintain their size all through the process and since their density is high, the majority fall more vertically than the seawater fallout (in same wind speed), and, where the initial deposits are high enough to be of concern the horizontal surfaces will be more highly contaminated than vertical ones.

For surfaces which are contaminated with more than a single layer of particles, only the bottom layer actually "contaminates" the surface: Most decontamination methods are capable of removing all the superficial layers of particles. If a method removes all but the surface layer (or, all layers and all particles greater than a given size in contact with the surface), then the amount left after decontamination is a constant, independent of initial deposit. For this process, the fraction of the mass of fallout remaining is

$$F_m = \frac{R_M}{y} \tag{6}$$

in which R_M is a constant dependent on the particle size and method of decontamination and y is the initial deposit in mass of (solid) fallout per unit area. The mass representation is used here to emphasize the fact the soil particles and not radioactive atoms are being acted upon during the contamination and decontamination process.

For surfaces which are contaminated with less than a single layer of particle, the above mechanism of removal is postulated for the fraction of the area which is covered with particles. Since the landing of a given particle on a given spot on a surface is a statistical process with the probability of the next particle landing on a "clean" spot being proportional to the clean area, the fraction of area covered at any time (say, at the end of fallout) will be

$$f = l - e^{-\alpha y} \tag{7}$$

in which α is a constant called the spreading coefficient; its value depends on the average particle size and the roughness of the surface. Thus the general equation for levels of initial deposit is

$$F_m = \frac{R_M(1-e^{-\alpha y})}{y} \tag{8}$$

The fraction, f or $(l - e\lambda^{y})$, becomes one for a single layer of particles at which level equation 8 reduces to equation 6.

Equation 8 is converted to radiation intensities by means of a quantity called the mass contour ratio $M\lambda rt$), in units of the ratio mass of fallout per unit area to r/hr. Briefly, the mass contour ratio is given by

$$M_r\lambda t) = \frac{f'k'A\lambda W^{(n-1)}}{bY(t)[a_{FP}(t) + a_I t]} \tag{9}$$

in which (see equation 5)

(1) $A\lambda W^n$ is the scaling relation for the mass of material thrown out of the crater,
(2) n is an empirical constant,
(3) $A\lambda$ is an empirical parameter depending on the scaled height or depth of burst, λ
(4) λ is defined as the height or depth of burst in feet divided by the cube root of the yield in pounds of TNT,
(5) k' is a converting yield to fissions and other units, and
(6) f' is the fraction of the crater mass which mixes with the radioactive elements.

In radiation intensities, equation 8 is

$$F_r = \frac{R_M(1-e^{-\alpha M_r(t)I_r})}{M_r(t)I_r} \tag{10}$$

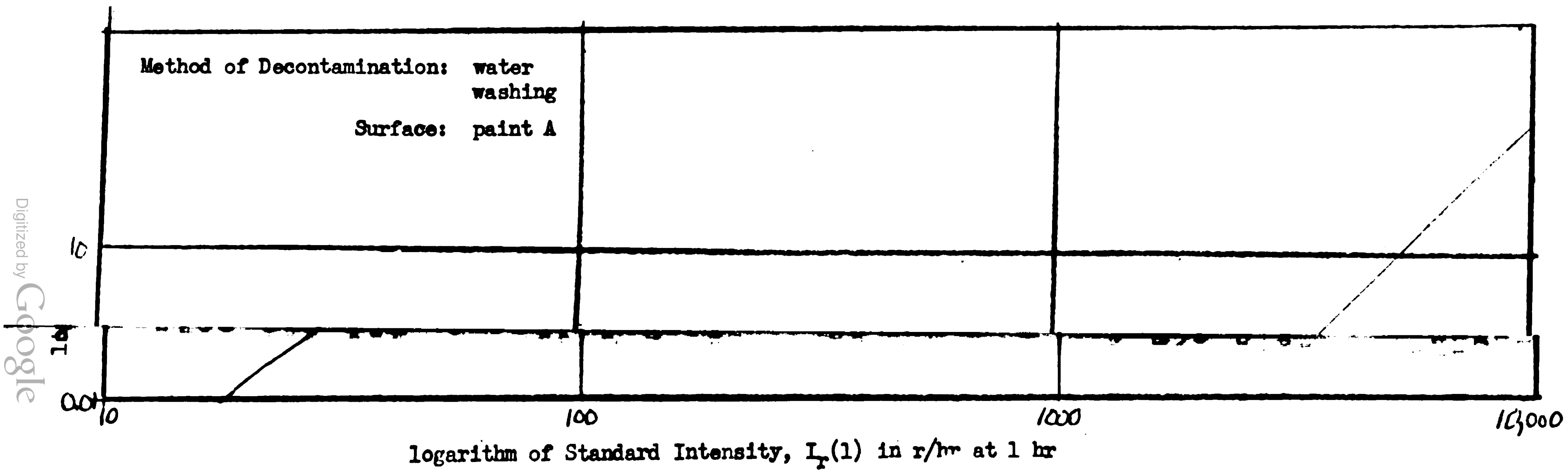
Harbor fallout

Harbor fallout can be either like sea-water fallout or like land fallout or a mixture of any combination of the two. A low yield burst on the surface of a deep harbor would give a sea-water fallout; a high yield detonation on the surface of a shallow harbor will produce a land fallout.

For the intermediate cases, the fallout will consist of sea water, harbor bottom (soil), bomb structural and target materials, and radioactive elements. The composition of fallout from harbor detonations can be described by their solid to liquid ratio, β.

Experimental data indicate that the additional phase (soil) to the seawater fallout induces only a negligible added interaction for most radionuclides and thus the total effect can be treated as a simple mixture of sea-water and land fallout. Where this is so a single representation can be made for all possible

Fig. 1 Predicted Radiation Levels after Decontamination at D + 7d as a Function of Standard Intensity in R/hr at 1 hr



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types of fallout. The general equation, in terms of the ratiation intensity at H+1 hr, is

$$F_r(f) = \left[\exp - \frac{\lambda\beta}{1+\beta} M_r(1) I_r(1)\right] \sum_{j=1}^{j=n} P_i(t) F_i(t) + \frac{R_M}{M_r(1)_r I(1)} \left[1 - \exp - \frac{\lambda\beta}{1+\beta} M_r(1) I_r(1)\right] \tag{11}$$

$$F_i(t) = a_{ir}(t)[I_r(1)]^{n_i(t)-1} + \frac{I_r(1)}{K_{ir}(1,t) + I_r(1)} \tag{12}$$

in which $P_j(t)$ is the fraction of the radiation intensity contributed by the radionuclides of element j; the sub r indicates an evaluation in terms of r/hr, the (1) indicates an evaluation in terms of r/hr at 1 hr after burst, and (t) indicates the parameter depends upon the time the surface has been contaminated—i. e. requires evaluation for the time, t, after burst when the decontamination is carried out.

The results of some laboratory scale data from synthetic fallout together with constants for a hypothetical nuclear bomb were used to evaluate other empirical constants. These were used to compute the final levels for a decontamination at 7 days after burst for initial levels ranging from 10 to 10,000 r/hr at 1 hr. The curves for a β of zero (sea-water fallout) to a $\beta \geqslant 1{,}000$ (land fallout) at selected intervals are plotted in figure 1.

At the present time, there is not enough data available to determine a similar three dimensional decontamination surface (or even a partial surface) for any available reclamation method-surface combination. Since large scale reclamations are expensive and difficult, the preferable experimental technique would be to investigate the nature of the decontamination surface for a series of method-surface combinations by use of small-scale experiments in the laboratory and to check these with a few carefully chosen large-scale experiments with sufficient correlation experiments to make proper adjustment of the equation parameters.

Contaminability of Targets

The vulnerability of targets to contamination by fallout must consider three parameters:

(*a*) Does the fallout contact the surface?
(*b*) Once in contact, does it remain on the surface?
(*c*) How tenaciously is it attached, i. e., how easy is it to remove?

Such information is important for:

(*a*) Predictions of the relative radiological hazard within the target complex so as to exploit this variability operationally.

(*b*) Predictions of the over-all vulnerability of structures that incorporate shielding.

(*c*) Design and planning criteria for recovery procedures.

(*d*) Design criteria to provide minimum vulnerability of targets.

Factors influencing the contaminability of targets are:

(*a*) Gross geometry and configuration which determine the airflow patterns around the target and/or influence the "drainage" of material from the target surfaces.

(*b*) Physical and chemical characteristics of surface materials, i. e., roughness, porosity, adsorbability, chemical reactivity, etc., which influence the "entrapment" of fallout and ease of loosening, removal, and transport of contaminant by decontamination processes and/or natural weathering.

(*c*) Meteorological conditions which determine the initial distribution of fallout, and its resuspension and/or redistribution.

(*d*) The physical and chemical characteristics of the fallout, i. e., type (deep water, harbor, or dry land), chemical state, particle size, density, etc., which influence the "flight" characteristics, the impact and retention characteristics and the tenacity with which it is held to the surface.

Various laboratory and field tests have been made of the contaminability of surface materials as related to fallout characteristics and angle of inclina-

tion.[1,2,3,4] The contaminability of targets as related to micrometeorology and geometry have not been studied directly, but some information has been derived from experiments with other objectives.[5] As an example, a ship was exposed to fallout from a deep-water detonation.[6,7] The fallout arrived in a 15- to 20-knot wind on the starboard beam.

The following results were obtained:

(a) The contamination level (240 readings) on horizontal surfaces varied from 16 percent to 400 percent of the average, i. e., the largest was 25 times higher than the lowest.

(b) The gamma radiation level at 3 feet above the deck varied by a factor of 10.

(c) The average contamination level for vertical surfaces varied from the average horizontal reading as follows:

1. Forward part of the ship: 40 percent of horizontal average.
2. Aft part of the ship: 20 percent of horizontal average.
3. Lee side: 10 percent of horizontal average.
4. Windward side: approximately equal to horizontal average.

(d) Test panels at the stern of the ship had an average contamination level on vertical surfaces three times higher than levels on horizontal surfaces.[8]

Such data cannot be extrapolated or used for predictions without a better understanding of all of the factors involved.

In another example, small buildings and panels of typical building materials were exposed to fallout from land detonations.[4] The contamination levels on typical roofing materials was as much as 300 times higher than that on typical wall panels; or a vertical to horizontal relationship of about 0.3 percent. For panels of the same material, vertical readings were about 10 percent of the horizontal.

The two examples indicate considerable difference in the vertical to horizontal relationships. The characteristics of the fallout appear to have had a considerable influence on this distribution. For instance, the land detonation normally produces a "dry" fallout composed primarily of material from the crater. One can expect masses of 3 to 300 grams of material per square foot to be associated with significant radiation levels at early times. The fallout being a dry powder has little tendency to stick on vertical surfaces.

The fallout from deep-water detonations is largely composed of sea water salts. However, much of the water may evaporate, leaving particles that are damp, semicrystalline masses of a sticky nature. They are capable of sticking to vertical surfaces.

As indicated very little is known of the overall problem of contaminability. It is obvious, however, that two assumptions often made, i. e., ((1) that the fallout is distributed homogeneously on a uniform infinite plane, and (2) that vertical surfaces are not appreciably contaminated) are subject to serious limitations. The ability of a tactical force and/or a civilian population to exploit the variability of the fallout pattern depends upon knowledge we do not have on contaminability.

The contaminability of personnel exposed to the fallout event or working and living in contaminated environments is largely unknown. A study[9] indicating the significance of beta contact hazard to personnel and a requirement for the mass decontamination of personnel, emphasizes the need for additional contaminability information.

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[1] Gevantman, L. H., B. Singer, T. H. Shirasawa, Contaminability of Selected Materials, USNRDL—TR-11.

[2] Gevantman, L. H., J. F. Pestaner, B. Singer, D. Sam, Decontaminability of Selected Materials, USNRDL–TR-13.

[3] Lane, W. B., R. K. Fuller, L. Graham, W. E. Shelberg, Laboratory Studies of the Decontamination of Repeatedly Contaminated Surfaces, USNRDL–TR-59 (confidential).

[4] Strope, W. E., Protection and Decontamination of Land Targets and Vehicles, Operation Jangle, project 6.2, AFSWP-WT-400.

[5] Lee, H., M. B. Hawkins, Some Considerations of the Geometrical Distribution of Fallout Radiation Sources Over Targets, Proceedings of the Shelding Symposium held at USNRDL October 17–18, 1956, vol. II (USNRDL report in preparation), secret.

[6] Molumphy, G. G., Captain, USN, Bigger, M. M., Proof Testing of AW Ship Countermeasures, Operation Castle final report, project 6.4, USNRDL 0012361.

[7] Lee, Hong, Technical Survey Data for Operation Castle, project 6.4, USNRDL TM–49.

[8] Maloney, Joseph C., et al., decontamination and protection, Operation Castle, project 6.5, AFSWP–WT–928.

[9] Broido, A., Teresi, J. D., requirements for mass decontamination of personnel, USNRDL–TR–38, April 1955 (secret RD).

Cost of Reclamation

Considerable data has been collected regarding the effectiveness of reclamation of targets contaminated by local fallout. The feasibility of applying these methods depends upon the following parameters:

(a) The time required to perform the reclamation must be short enough to make an appreciable saving in radiological exposure to mission personnel,

(b) The radiation exposure to reclamation personnel must be justified by the saving in exposure of mission personnel,

(c) The effort (manpower) and logistics required to reclaim the target must be compatible with the total effort available.

Thus, the cost of reclamation as measured in operating time, effort, radiation exposure, equipment, and supplies is an important determination.

It is impossible to generalize on these quantities for they are influenced by many factors.

The type of fallout, whether it be from a deep water, harbor or land detonation, influences the rate and/or method of decontamination. A deepwater-type fallout can be removed only to an extent of about 60 percent for a firehosing, scrubbing operation on ships,[1] the rate being about 40 square feet per minute. The same decontamination procedure at 6 times the rate of operation on a paved area contaminated by dry-land-type fallout will yield a removal of about 98 percent.[2] To achieve an equivalent removal on the ship, a surface removal technique would be required. Typical rates of operation are about 20 feet per minute for paint stripping[3] and about 7 feet per minute for removing a ⅛-inch thick layer of wood from the flight deck.[4]

The amount (or mass) of fallout on a surface influences the rate, particularly for harbor and dry-type fallout that must be transported over horizontal surfces for considerable distances. The following table shows an example of how the rate decreases with increasing masses of dry fallout for motorized flushing.[2]

Dry fallout gm/ft:[2]	*Motorized flushing rate, ft.²/min.*
10	670
33	650
100	580
330	300

The mass of fallout has no effect on the rate of operation for surface removal or earth moving techniques.

The rate of operation is influence by the surface characteristics of the target, rough surfaces, e. g., wood shingles, requiring longer time than smooth, e. g., metal surfaces. The following table is an example of the influence of surface roughness on rate of operation:[2]

Firehosing of dry contaminant

Material	Effectiveness (percent removed)	Rate (ft²/min/hose)
Corrugated metal	97	65
Composition shingles	95	50
Wood shingles	89	35

The rate of reclamation by earth moving is influenced by soil characteristics. Standard earth moving practice has developed considerable information on this subject.

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[1] AFSWP, ITR 1323, preliminary report, Operation Redwing, project 2.9, Standard Recovery Procedure for Tactical Decontamination of Ships. Confidential.

[2] Field Evaluation of Cost and Effectiveness of Basic Decontamination Procedures for Land Target Components, Sartor, J. D., Curtis, H. B., etc., USNRDL–TR in preparation. Unclassified.

[3] Rates approaching 50 square feet per minute are possible if removal of only the surface layer of paint gives the required reduction in radiation intensity.

[4] Proof Testing of AW Ship Countermeasures, Operation Castle, project 6.4 WT-927, Molumphy, Bigger. Confidential.

The degree of mechanization obviously influences rate of operation. The following example compares firehosing rate with that of motor flushing for harbor-type fallout. Also shown are the influence of mechanization on effort and radiation exposure.[2 4]

Criteria for comparison	Actual performance or cost		
	Firehosing	Motorized flushing	Relative cost FH/MF
1. Operating rate per unit, hr/10^6 ft^2	222	30	7.4
2. Personnel required per unit	5½	2	2.75
3. Effort (direct labor), man-hr/10^6 ft^2	1,210	60	20.0
4. Radiation shielding factor	1.0	0.5	2.0
5. Relative cost in radiation dose	1,210	30	40.0

Target complexity obviously influences rate of operation. For optimum performance, spacings between target components must be large enough to permit mechanized equipment to be used.

A simplified example will help indicate the time, manpower, and basic supplies required for recovery of a target complex. The following criteria are assumed:

(a) Target: City of San Francisco.
(b) Fallout: Harbor-type at 33 gms/ft².
(c) Area to be recovered: About 25 square miles consisting of—
1. All paved areas.
2. All industrial and commercial areas and buildings.
3. 50 percent of the park areas.
4. 10 percent of the residential areas and buildings.
(d) Methods: Firehosing and earth moving.

The following table indicates an estimate[5] of the cost of reclaiming these critical areas:

Cost of decontaminating critical areas of San Francisco through use of available firefighting and earth moving equipment for removing slurry contaminant

	Firehosing			Earth moving, land areas	Grand total
	Roofs	Paved surfaces	Subtotal		
1. Time to complete decontamination (24-hour days)	16.8	11.7	28.5	13	
2. Direct labor (number of men)			4,000	2,800	6,800
3. Total labor, direct and support (number of men)			6,000	4,900	10,900
4. Total effort (8-hour man-days)	101×10^3	70×10^3	171×10^3	64×10^3	235×10^3
5. Labor cost at $10 per man-day			$\$1.71\times10^6$	$\$0.64\times10^6$	$\$2.35\times10^6$
6. Water required for decontamination (gallons)	362×10^6	314×10^6	676×10^6		
7. Fuel required (gallons):					
(a) Gasoline	145,000	101,000	246,000	95,000	341,000
(b) Diesel fuel				195,000	195,000

As can be seen, the reclamation is feasible in what appears to be a reasonable time. The amount of equipment required is within the capability of existing sources in San Francisco. The manpower is not too excessive considering the numbers of people available. The water requirements are within the capability of the normal supply. Fuel consumption is less than normal daily requirements. The greatest problem would undoubtedly be that of organizing, training, supervising, and controlling 11,000 men.

Automatic decontamination devices such as the washdown system have, as an important advantage, the capability of reclamation at very early times with no expenditure of manpower or radiation exposure. They can be extremely effective (i. e., removal of 90–95 percent) even on sea-water-fallout.[4] However, they do require expenditure of funds before the war begins.

[5] Engineering Approach to Radiological Decontamination, Hawkins, M. B. (Paper to be given ASME semiannual meeting, San Francisco, June 1957.) Unclassified.

THE NEED FOR A NATIONAL PROGRAM IN NUCLEAR COUNTERMEASURES

The full exploitation of nuclear weapons and nuclear power requires that full preventive measures be employed at all times to keep potential exposure below hazardous levels, *and* that the capability of reclamation after any nuclear mishap be high.

The current policies of the AEC and DOD, backed by the very competent Health and Safety Division in the AEC installations, have provided a generally satisfactory national program based on *preventive* and control measures. No similar program exists to fulfill the reclamation requirement, or to prepare the way for successfully coping with a general increase of radioactive background above that imposed from natural sources. Such an increase is inevitable—both on a general scale and on a more limited scale. The general buildup is predominantly related to weapon detonations. The more limited scale is confined to such areas as the exclusion zones of the Nevada test site, the Reactor Test Station, Arco, Idaho, etc. From the other extreme, there is an increasing demand to establish contamination specifications for the general release of previously contaminated equipment into the established industrial channels.

It is proposed that a positive national program of nuclear countermeasures development be undertaken to add preprotection and reclamation capability to the established preventive measures.

Four completely different types of end-use application are apparent:

(1) Increasing the nuclear resistance of military operating forces in the field.

(2) Continental defense of the United States in time of total nuclear war.

(3) Reclamation from a nuclear mishap in times of peace.

(4) Adaptation of the established economic system to absorb the applications of nuclear energy that are already developed, or under development.

The four applications are common in that one is faced with the impact of radiation and radioactivity on the civilian and/or noncombatant society. The control techniques used during the research, development, and production phases are no longer sufficient since these techniques rely solely on control and preventive measures.

The four applications differ in that the criteria relating the nuclear or radiological environment to the permissible dose or acceptable hazard are not completely common.

However, much of the research and development up to the point of final application is interchangeable. A unified research and development program should have a large payoff value on all four fronts. It also appears that the DOD, AEC, FCDA, and possibly the PHS all have a vital interest in such a unified program.

SUMMARY OF NUCLEAR WEAPON COUNTERMEASURE SYSTEM DEVELOPMENT PROGRAM PROPOSAL (SPECIAL TEST PROGRAM COMPONENT)

This memorandum summarizes the proposals advanced by the United States Naval Radiological Defense Laboratory as representing the fastest and most economical way of developing a national capability in nuclear weapon countermeasures. This proposal has formed the basis of discussions with Mr. R. L. Corsbie and Dr. A. W. Bellamy, representing the Atomic Energy Commission, concerning the manner in which nuclear weapon tests could be more profitably exploited. The same proposal has been discussed with the FCDA Planning Office, but has not been formally developed.

To insure the greatest level of national readiness in minimum time, the nuclear weapon countermeasure system must be developed with the same care that has gone into the development of the offensive weapon systems. It is proposed that a nuclear weapon countermeasure system development program be established, and that a *proof test* of the proposed system be made at a special test to be conducted in accordance with the attached schedule. This test will:

(1) Proof test proposed standard shelter designs.

(2) Proof test proposed rapid reclamation systems.

(3) Establish an experimental basis for determining criteria required to achieve final recovery.

Such a program cannot succeed if projects are submitted by invitation to all agencies that may have an interest in the subject. The test projects must be carefully planned to proof test an integrated system and must carry through all three time phases: emergency, operational recovery, and final recovery. The United States Naval Radiological Defense Laboratory believes it has the competence to develop such an integrated system. Adequate criteria exist to justify an operational development program of both emergency and operational recovery phases. Adequate criteria do *not* exist to establish feasible systems for the final recovery phase. Therefore, this test must be used to aid in the experimental determination of such criteria including food management and agricultural reclamation. The capability of existing instrumentation and doctrine to provide the required radiation and operational control data will be able to be determined realistically.

This program is only one part of the required national weapon countermeasure program. However, it provides the essential base against which real progress can be evaluated.

The proposals submitted to Mr. Corsbie for Operation Plumbbob are developmental projects covering some aspects of the emergency and operational recovery plans.

Outline of Essential Timetable

R&D program leading to selection of system components and establishment of necessary projects	Test date minus 3 years	
	Test date minus 2 years	Site selection and program scope completed
	Test date minus 1 year	Submission of complete test program plan
Construction, equipment procurement, training		
	TEST DATE	
Operational recovery begins		Emergency phase complete
Shelters, situation appraisal, etc.		
Transition to final recovery begins	Test date plus 6 months	Final report on emergency phase program
	Test date plus 9 months	Operational recovery complete
	Test date plus 18 months	Final report on operational recovery phase program
Experimental program to measure incorporation of critical elements into the environment and their uptake into animals. Agricultural reclamation experiments.	Test date plus 3 to 5 years	

Evaluation of the state of knowledge relating to radiological countermeasures development [1]

	Continental defense	Peacetime application
Transport mechanism	A	C
Nuclear and chemical properties	A	B
Contamination-decontamination phenomena	C	C
Reclamation methods	B	C
Component development	C	C
Shielding and terrain effects	B	B
Shelter development	B+	(2)
Final recovery	C	C
Systems development and analysis	B	B

[1] This table was developed by Dr. Paul C. Tompkins, USNRDL, Mr. R. Corsbie, and Mr. J. Deal, DBM of the AEC, to guide the development of projects to improve the nuclear weapons defense capability of the Atomic Energy Commission. It has been examined by the technical staff of the USNRDL and is considered to be a fair evaluation of the current state of real knowledge.
[2] Not applicable.

NOTE.—State of knowledge and effectiveness of application based on the ability to apply determinable numbers in a wide range of actual cases:
A—Adequate for practical applications
B—Inadequate for practical applications
C—Little known

(Submitted by Department of Defense)

U. S. NAVAL RADIOLOGICAL DEFENSE LABORATORY

SAN FRANCISCO, CALIF

From: Commanding officer and director.
To: Chief, Bureau of Ships (code 110).
Subject: Congressional hearings before the Joint Committee on Atomic Energy concerning the nature of radioactive fallout and its effects on man, scheduled for May 27 through June 7, 1957.
Reference:
(a) Ch, BuShips ltr A18 (110) Ser 110–1447 of June 6, 1957.
(b) CO and Dir, USNRDL Conf ltr 900–0801 PCT: iem of May 16, 1957.
(c) CO and Dir, USNRDL ltr 900–803 RCL: rts of May 23, 1957.
Enclosure: (1) Biographies of contributors to written statements submitted for subject hearings.

1. As requested by reference (a), enclosure (1) forwards biographies of contributors to the written statements submitted for the subject hearings, arranged in an alphabetical listing. The authors and identifying titles of the USNRDL survey of various aspects of radiological fallout from nuclear weapons are given below in the order submitted.

(a) Reference (b):

I.	Prediction of Fallout	E. A. Schuert C. F. Ksanda
II.	Measurement of Fallout	T. T. Triffet
III.	Physical and Radiochemical Properties of Fallout	N. E. Ballou C. W. Adams
IV.	Environmental Aerosol Analysis	A. L. Baietti
V.	Radiological Countermeasures	C. F. Miller

(b) Reference (c):

I.	Mass-Activity Relationships Derived from Fallout Measurements.	C. F. Miller
II.	Relation of Radioactive Decay to Countermeasures.	C. F. Miller
III.	Physical Chemistry of Fallout as It Relates to Decontamination Countermeasures.	C. F. Miller
IV.	Contaminability of Targets	M. B. Hawkins
V.	Cost of Reclamation	M. B. Hawkins

VI. General information on a nuclear countermeasures program:
- A. The Need for a National Program in Nuclear Countermeasures.
- B. Summary of Nuclear Weapon Countermeasure System Development Program Proposal.
- C. Evaluation of the State of Knowledge Relating to Radiological Countermeasures Development.

} P. C. Tompkins

2. The material submitted by the USNRDL was reviewed and edited by Drs. E. P. Cooper and E. R. Tompkins. Because of their valuable contributions, their biographies are included in enclosure (1).

By direction:

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DEPARTMENT OF THE NAVY

OFFICE OF NAVAL RESEARCH

Washington, D. C.

From: Chief of Naval Research.
To: Chief of Legislative Liaison.
Subject: Congressional hearings before the Joint Committee on Atomic Energy concerning The Nature of Radioactive Fallout and its Effects on Man, scheduled for May 27 through June 7, 1957.
Reference: (a) OLL: INV: ACJ: gms memo 6–1182 of June 3, 1957.

1. In accordance with reference (a), the following biography is submitted:

Lockhart, Luther B., Jr.

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A. B. METSGER,
Deputy and Assistant Chief of Naval Research.

HEADQUARTERS, AIR WEATHER SERVICE,
MILITARY AIR TRANSPORT SERVICE,
UNITED STATES AIR FORCE,
Washington, D. C., May 17, 1957.

STATEMENT BY LEROY H. CLEM [1] OF THE AIR WEATHER SERVICE ON FALLOUT PREDICTION

The prediction of radioactive fallout is a combined meteorological and radiochemical problem. The mission of the Air Weather Service does not include any treatment of the radiochemical portion of the problem but is confined to the indication under emergency wartime conditions of the effect of only the meteorological variables on the transport of radioactive debris during its fall back to earth within a few hundred miles of the site of a nuclear detonation. To accomplish this mission requires accepting certain rather gross assumptions about such nonmeteorological variables as the initial distribution of contaminated particles in the stabilized cloud and the particle fall rates. Thus, given these gross assumptions, the only additional factors with which the Air Weather Service forecasters are concerned are the time and location of the occurrence of a nuclear detonation and the best estimate of the wind field through which the radioactive debris will fall.

The idealized meterological solution to this problem involves the computation of a whole family of three-dimensional trajectories starting from various levels of the atomic cloud. By considering changing wind conditions, these trajectories represent the fall paths of a variety of particles (of differing size and shape) which were present at the various levels in the cloud when it stopped rising. Such a solution is beyond the present state of the science of meterology. Therefore, the Air Weather Service, as well as other agencies, had to make certain simplifying meterological assumptions in order to be able to handle the forecast problem.

The generally accepted method is based on the following main assumptions:

(*a*) The winds at selected levels in the middle of layers (e. g., 10,000 feet thick) are representative of the windflow that would effect the drift of the particles while they are falling through that layer.

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[1] Bachelor of science degree, Brown University; certificate for graduate meteorological engineering, New York University; master of science degree in meteorology, Massachusetts Institute of Technology; 13 years of professional experience in meteorology; during World War II served as an aerological officer in the Navy; several years experience with the U. S. Weather Bureau; serves as the expert on fallout-prediction problems, high level wind problems and forecast capabilities. Assigned to the Technical Service Branch, Technical Requirements and Services Division of Scientific Services of Headquarters, Air Weather Service. (Submitted by Department of Defense.)

(*b*) The wind sounding (observed or forecast) for the upper-level winds applicable at the point of detonation is representative of the windflow throughout the course of the ensuing fallout.

It is believed that assumption (*a*) does not introduce much error; however, assumption (*b*) is both the heart of the technique and the most questionable of these two assumptions. Although experience has shown that persistence forecasts (implied in (*b*)) of upper-level winds are equal to or better than other available forecast methods for the first few hours, variability of the wind, when coupled with the inaccuracies of wind observations and forecasts, introduce sizable errors in the method. The average error in the resultant 6-hour forecast fallout plot derived from this method is of the order of ± 10 to ± 30 degrees in direction and 30 to 40 percent in distance. The forecast errors involving fallout coming from the higher levels of radioactive clouds formed by large weapons are relatively smaller than those for fallout from the lower levels of the clouds.

However (even in view of these inaccuracies), by using the stated meteorological assumptions, it is possible to compute the most probable geographical area that may be contaminated by radioactive fallout following a surface or near-surface burst of a nuclear weapon. There are more sophisticated and time-consuming computational techniques available, involving more complex assumptions than (*b*) which are supposed to take care of some of the variability of the wind. However, evaluation tests have indicated that the slight decrease in the resultant errors from using these more complex methods does not justify the extra computational time and effort involved. The Air Weather Service method, based on a very simple and versatile 6-hour wind-vector technique, is equally useful in this country as well as overseas and can be evaluated for any desired area on the earth's surface or at altitudes normally used by aircraft. This method consists of adding the wind vectors from the layers through which the particle will fall and then (with an assumed fall-rate) a fallout plot is developed from this. This results in a time-space plot which delineates the areas which may receive fallout and the expected time of occurence. It should be noted that no attempt is made in this method to forecast levels of radiation intensities, relative or absolute.

Although this method for forecasting the close-in areas which are expected to be contaminated by falling radioactive debris does not achieve the accuracy and precision ideally desired (because of many unresolved factors, some of which are nonmeteorological), its accuracy (± 10 to ± 30 degrees in direction and 30 to 40 percent in distance from ground zero) is in line with the current state of the science. There are no techniques available today which can provide more than very generalized answers in a forecast situation involving large weapons.

STATEMENT BY COL. B. G. HOLZMAN[1] AND COL. NORAIR M. LULEJIAN,[2] AIR FORCE RESEARCH AND DEVELOPMENT COMMAND

Question. How does your organization predict fallout, given weapon yield, height of burst, type of terrain, and meteorological conditions? How reliable do you feel these forecasts are?

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[1] Born: Los Angeles, Calif., January 25, 1910. 1931: B. S., California Institute of Technology. 1933–34: Ph. D., candidate graduate study, California Institute of Technology. June 1945 to July 1945: Alamagordo, N. Mex.: meteorological adviser on first atomic test. August 1945 to January 1946: Asheville, N. C.: Chief, Research and Evaluation Division, Weather Service. February 1946 to August 1946: Washington, D. C., and Bikini, Marshall Islands: Atomic bomb tests, staff weather officer, Joint Task Force 1. September 1946 to August 1947: Washington, D. C.: Headquarters, air staff, research and development officer for atmospheric sciences. September 1947 to June 1948: Washington, D. C., Eniwetok, Marshall Islands: Atomic bomb tests, staff, weather officer, Joint Task Force 7; executive officer, long-range detection (AFOAT–1). July 1948 to June 1950: Washington, D. C.: Chief, Geophysical Sciences Branch, research and development, Headquarters, USAF. June 12, 1950, to August 23, 1951: Washington, D. C.: Chief, Research Division, assistant for atomic energy, headquarters, USAF. January, February, 1951: Nevada: Operations consultant to AEC, Nevada ranger, atomic tests. August 23, 1951, to June 17, 1952: Washington, D. C.: National War College. June 17, 1952, to September 1, 1952: Baltimore, Md.: Headquarters, Air Research and Development Command. September 1, 1952, to May 30, 1955: Albuquerque, N. Mex.: Deputy for Research and Development, and Chief of Staff, Special Weapons Center, Kirtland Air Force Base. May 30, 1955, to present: Baltimore, Md.: Director, Air Weapons, Headquarters, Air Research and Development Command. (Submitted by Department of Defense.)

[2] Native of Hawthorne, N. J., is a graduate of Columbia University (B. S. in 1939); worked as a research chemist for Ortho Products, Inc., in Elizabeth, N. J., for a period of

Footnote continued on following page.

Answer. The Air Force Research and Development Command has developed a simple method to predict the general area within which fallout may occur. An attempt was made for several years to develop a more rigorous treatment of the fallout problem; however, this approach was abandoned because of the inherent time and space variability of the atmospheric winds which introduces large errors in all fallout predictions. It is the opinion of Air Force Research and Development Command that in view of the large errors introduced by the variability of the winds, it is pointless to attempt a precise model of the radioactive distribution in the atomic cloud. The fallout pattern influenced by different types of terrain are completely masked by the very large errors introduced because of variability of the winds. Experience during past atomic-test operations has verified the fact that even when zero-hour-measured winds were used, thus eliminating all wind-forecast errors, the actual fallout never occurred in the exact region indicated by the observed winds. There was always a displacement varying up to 45° of the actual fallout from its calculated position. The reason for this is simple. The observed winds are valid over the target area for a relatively short time. Fallout may reach a distance of 150–250 miles downwind and it may take 6–18 hours for the local fallout to be completely deposited on the ground. During this 6–18 hours the winds change both in direction and in speed. There is not only this time variation, but also the space variation. In other words, the winds aloft over ground zero are not necessarily the same as winds 150 miles downwind. Furthermore, the method of measuring winds by the use of balloons introduces another serious error because of the inability to specify the true wind profile directly over ground zero.

It is questionable whether the time and space variability of the winds could be forecast with an accuracy exceeding ±15° in the direction of the winds. An error of 15° would spell the difference between an airbase or a city receiving either no radiation at all or possibly lethal concentrations of radiation from the local fallout of a single weapon.

We have considered fallout from the offensive and defensive points of view. For defensive purposes before we can make any reasonable estimates of the local fallout plot we need to know the total yield as well as the fission yield of the weapons, height of burst, and coordinates of ground zero. Even with all this information it will be impossible to delineate the fallout pattern with sufficient accuracy to predict whether a given military installation downwind of ground zero would receive no, little, or lethal concentrations of radiation. For offensive use a further complexity is introduced because most probably very little if any reliable meteorological information will be available over enemy territory. Therefore, in spite of our knowledge of the yield, height of burst, and ground zero on bombs, the fallout pattern over enemy territory would be equally if not more difficult to predict.

When many multimegaton weapons are exploded, the calculation of reasonably accurate fallout patterns becomes even more difficult. The validity of the requirement for ascertaining fallout patterns under these conditions becomes even more questionable because lethal contamination will occur over large overlapping areas regardless of the meteorology.

However, the above should not be construed to mean that we are unable to make generally correct predictions; for instance, as to what countries or large areas shall lie inside or outside the dangerous part of fallout patterns from distant bursts. A choice of burst height that prevents the fireball from touching the earth, essentially eliminates local fallout.

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2 years; entered military service in September 1942, and enrolled as an air cadet in meteorology in January 1943 at Grand Rapids, Mich.; received his commission as second lieutenant in September 1943; returned from overseas early in 1946 and served with Headquarters Air Weather Service until September 1946, after which time he was transferred to Headquarters, USAF, in the Pentagon. He left Headquarters, USAF, to enter a 3-year course in radiological engineering in September 1948; assigned to Headquarters, ARDC, in Baltimore since June of 1952. He is Chief of the Nuclear Applications Division of the Directorate of Air Weapons. (Submitted by Department of Defense.)

STATEMENT BY DR. DONALD M. SWINGLE[8] OF THE ARMY SIGNAL CORPS, EVANS, S. C., LABORATORY, FOR SUBMISSION TO THE JOINT COMMITTEE ON ATOMIC ENERGY

Question. How does your organization predict fallout, given the weapon yield, height of burst, type of terrain, and meteorological conditions? How reliable do you feel these forecasts are?

Answer. 1. The principles of fallout prediction used in the Signal Corps method are outlined below:

(*a*) The prediction procedure described assumes a surface burst of a nuclear weapon. Given the weapon yield, the dimensions of the cloud are estimated from a survey of previous test data. (See discussion below.)

(*b*) The cloud is split into layers, on the basis of available data on particle-size distribution, and the particle sizes in each layer are considered.

(*c*) Where each particle size in each part of the cloud will land is determined by trigonometry, considering rate of fall and the effect of wind. It is assumed that the latest available wind data is representative.

(*d*) Then the ground position of arriving fallout is plotted and overlapping contours are added together.

(*e*) A meteorological contour analysis of the resulting pattern is made and this is analyzed for dose-rate information.

(*f*) The time of arrival on the ground of each particle size for each original slice is calculated and analyzed for *time of arrival* and *time of ending*, if wanted, of fallout material.

(*g*) From consideration of the time of arrival and dose rate, the *total dose* for 48 hours is approximated.

In the above procedure, terrain has not been specifically considered.

2. The effective radiological activity predicted would be affected by the estimated height of the cloud. The ratio of fission to total yield of the burst will affect the estimated dose rates and the total dose.

3. If the height of the cloud is known, the height to which wind data is required is immediately known. Assuming the height of the cloud is not known, the height and diameter may be estimated from the meteorological conditions. The criterion for estimating the cloud height is the height of the tropopause. This is accomplished by adjusting the basic pattern design for location of burst and for the season.

4. The accuracy of fallout prediction is directly related to the accuracy of the basic information. The degree of reliability of the several factors and the variation of wind with time and space prohibit exacting prediction. The Signal Corps is studying the question of attainable accuracy. But data for vertification of pattern design is limited. Considering the factors outlined above and when the fission to total yield is known, it is hoped to attain fallout prediction within a factor of 2 for points within contour lines of 100 roentgens per hour or greater.

5. The details of a Signal Corps draft method of fallout prediction are being reviewed and the method is being modified. Consideration is being given to the effect of time and space variations of the wind. The present method utilizes an effective wind consideration at the point of burst to be applied throughout the pattern computation.

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[8] Physicist GS–14. Chief, Meteorological Techniques Secton, Meteorological Branch, Physical Sciences Division, Evans Signal Laboratory, U. S. Army Signal Engineering Laboratories, Fort Monmouth, N. J. Graduated Theodore Roosevelt High School, Washington High School, Washington, D. C., 1939; bachelor of science in math-science from Wilson Teachers College, 1943; master of science in meteorology from New York University, 1947; master of arts in engineering science and applied physics from Harvard University, 1948; doctor of philosophy in engineering science and applied physics from Harvard University, 1950. American Meteorological Society, World Meteorological Organization Working Groups, Institute of Radio Engineers, American Geophysical Union, American Association for the Advancement of Science, American Institute of Electrical Engineers, ad hoc groups under established coordinating agencies. Professional engineer in States of New York and New Jersey. During World War II participated in the first modification of existing radars for the specific purpose of weather observation. He has been intimately connected with later development of equipment and the development of radar techniques for observations of storms, precipitation areas, and other specialized parameters. Techniques concerned with local meteorology of particular importance to Army operations is another concern of his. Leading Army scientist concerned with methods of predicting fallout. His present efforts are directed toward a practical field method of prediction which will lead to information of sufficient detail for Army use. (Submitted by Department of Defense.)

MAY 24, 1957.

TECHNICAL PRESENTATION FOR THE JOINT COMMITTEE ON ATOMIC ENERGY HEARINGS ON THE SUBJECT, THE NATURE OF RADIOACTIVE FALLOUT AND ITS EFFECTS ON MAN, MAY 27-29 AND JUNE 3-7, 1957

Specifically on—

Topic VI. Atmospheric Transport, Storage, and Removal of Particulate Radioactivity
Topic VII. Local Fallout
Topic VIII. Delayed Fallout

Submitted by James G. Terrill, Jr.,[a] Chief, Radiological Health Program, Division of Sanitary Engineering Service, Public Health Service, United States Department of Health, Education, and Welfare

VI. ATMOSPHERIC TRANSPORT, STORAGE, AND REMOVAL OF PARTICULATE RADIOACTIVITY

Public Health Service fallout activities have emphasized the collection of data on the actual exposure of people which data can be used to modify operational procedures to reduce the exposures and to serve as a basis for studying possible chronic radiation effects.

B. Local fallout

Local fallout is initially of concern as an acute external gamma or beta irradiation hazard. For this reason our off-site radiological safety operations in Nevada and in the Pacific are based on external gamma readings obtained with portable survey instruments. This system of operation is based on the assumption that beta concentrations during this period are substantially in proportion to the gamma intensities. This assumption has been confirmed, in general, by results of beta measurements of air samples collected during the fallout periods in Nevada. Local fallout may, and has become of concern as an internal beta emitter after its decay to a level at which the gamma irradiation is no longer of concern from the standpoint of acute effects. Up to this time the Service has not attempted to measure alpha concentrations in local (or delayed) fallout although the amounts are presumed to be low.

A report of local fallout sufficiently detailed to be used for public health purposes is the Report of Off-Site Radiological Safety Activities from Operation Teapot conducted at the Nevada test site in the spring of 1955, prepared jointly by the Las Vegas Branch Office of the Atomic Energy Commission and the Public Health Service.[1] Comments concerning the predictability of local fallout and observed patterns of local fallout will be based on this report.

The Teapot report outlines Public Health Service responsibilities and the supporting services, including air support, provided by other agencies.

Data gathered during this operation make it possible to:

1. Compare predicted fallout with the fallout as it actually occurred;
2. Compare the radioactive cloud path with the deposition of activity on the ground; and
3. Report on observed patterns of local fallout in terms of external gamma radiation.

1. The predictability of local fallout.—Fourteen devices were detonated during Operation Teapot. In reviewing the data on predicted and measured fallout from these detonations, it was found that in 5 cases the prediction is in substantial agreement with measured fallout, while in 6 cases the actual deposition of fallout was significantly at variance with the prediction. Three devices were air detonated and no fallout prediction per se was used. Chart I illustrates a case where the fallout prediction compares favorably with the fallout which actually occurred. Chart II shows a typical deviation from the predicted fallout, while chart III shows a major deviation from the prediction.[1]

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[a] Graduated from the University of Cincinnati in 1937 with a degree in civil engineering. Studied public health engineering at the Massachusetts Institute of Technology Graduate School from 1938-41. Since 1941 he has been active in the Public Health Service. Participated in the first Bikini tests. During the period 1948-51 he studied radiological defense under the sponsorship of the Armed Forces special weapons project at the U. S. Navy Postgraduate School and the University of California. He participated in and directed the Public Health Service activities related to the Nevada and Pacific test operations during 1953-57. Active in radiological committees of the American Society of Civil Engineers and the American Public Health Association. Member of the National Committee on Radiation Protection and the Nuclear Standards Board of the American Standards Association. Presently chief of the radiological health program, Division of Sanitary Engineering Services, Public Health Service. (Submitted by witness.)

[1] Report of Off-Site Radiological Safety Activities, Operation Teapot, Nevada test site, spring 1955.

It should be emphasized that these data are for gamma radiation only and represent only particulate material fallen from the cloud. They do not take into account isotopes, such as iodine, that may be in a gaseous form and may not follow the fallout pattern. We plan to study this as well as other problems related to fallout exposure during and following Operation Plumbbob as a part of our off-site operation carried out under agreement with Albuquerque Operations Office of AEC. This work also has the concurrence of the Division of Biology and Medicine of AEC.

CHART 1

FALLOUT PATTERNS

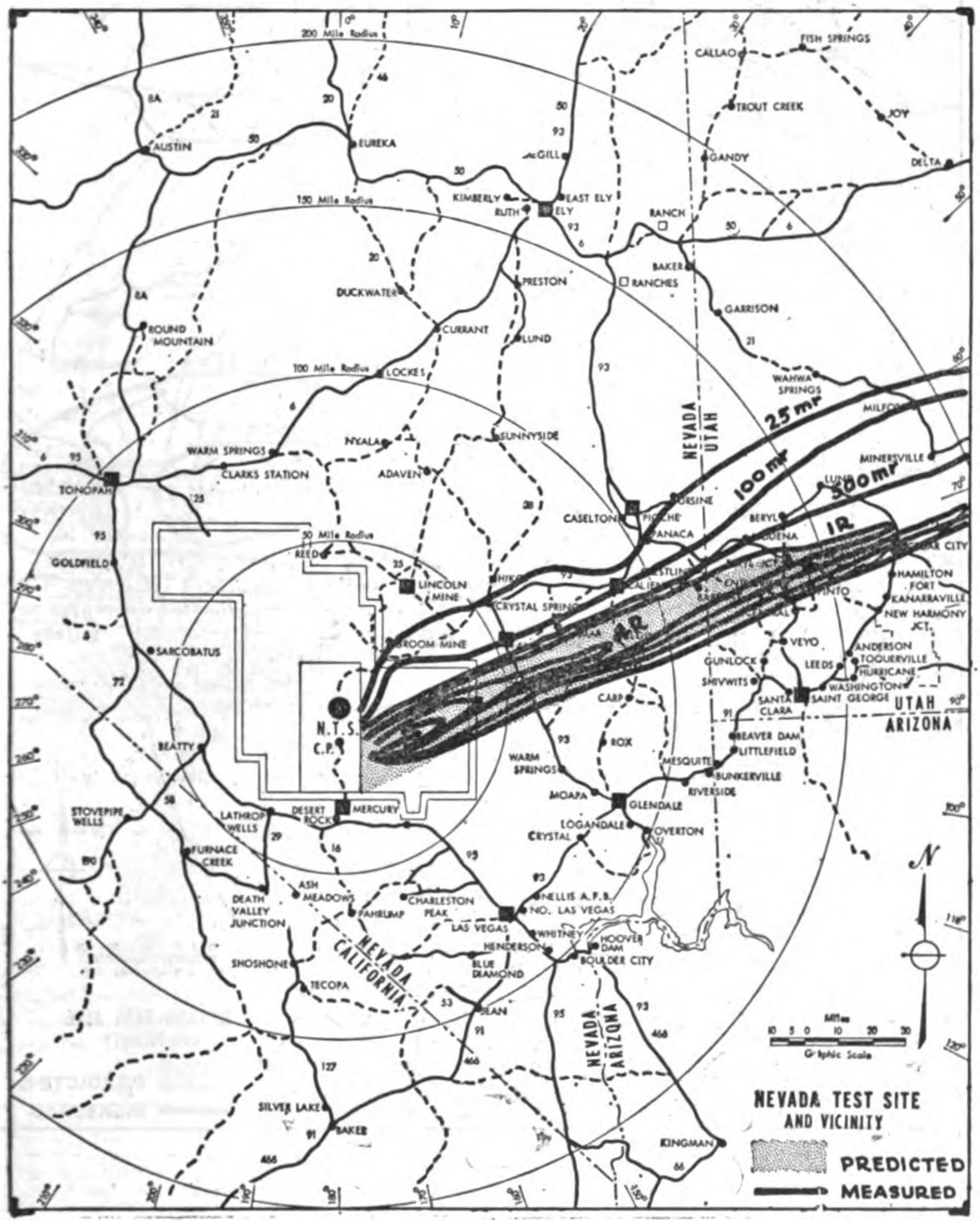

CHART 2

FALLOUT PATTERNS

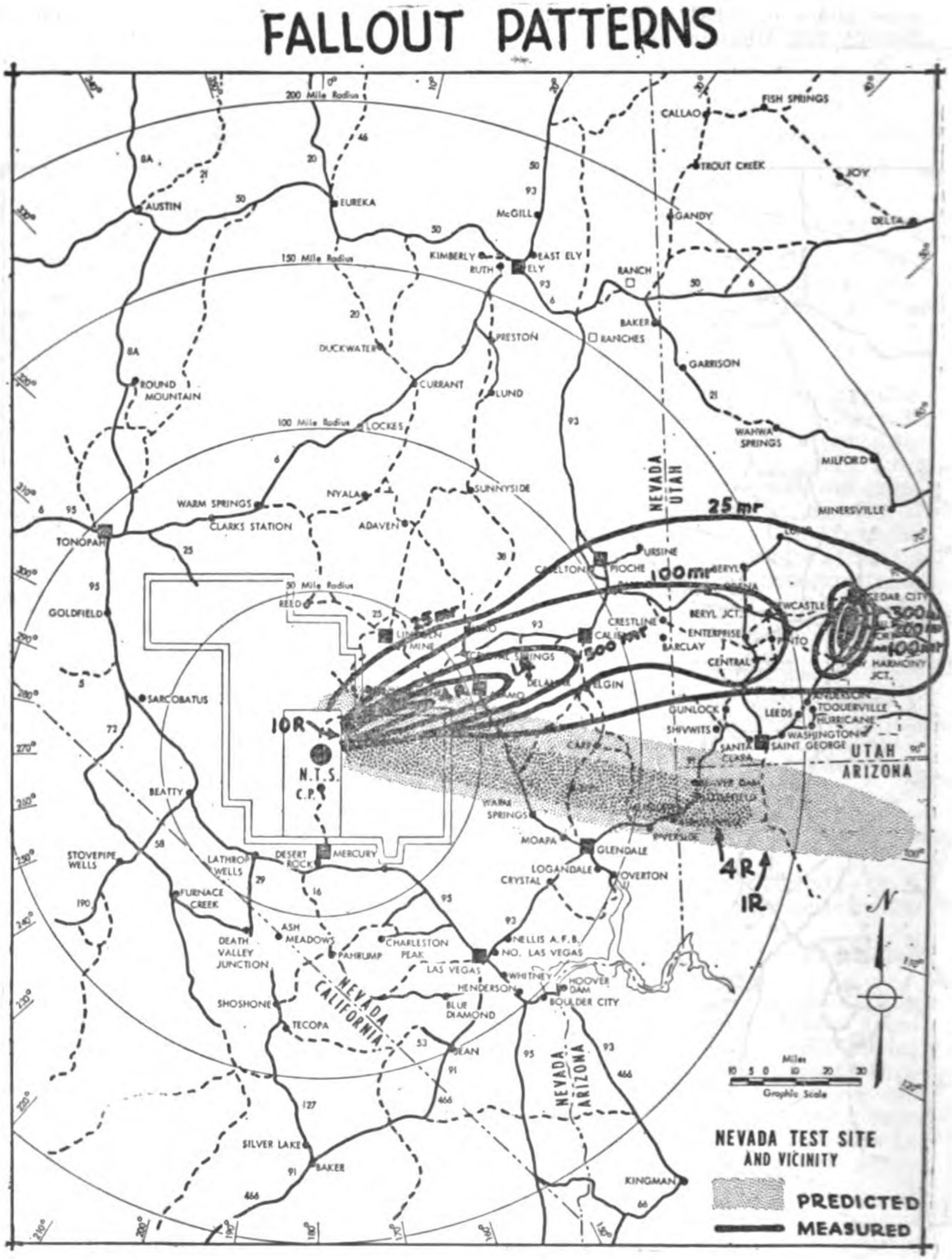

CHART 3

FALLOUT PATTERNS

Data from this report also indicates that cloud tracking with planes will generally give only an indication of the direction of fallout and cannot be relied upon for precise knowledge concerning deposition on the ground.[1] Most of the time it will give an idea of the direction from the point of detonation in which the fallout will occur, but this is not always the case. For public health emergency action it is not possible to depend entirely on cloud tracking as this will not always result in a reduction in exposure.

2. *Observed patterns of local fallout.*—A good deal of data has been obtained in the off-site area surrounding the Nevada test site from which fallout patterns can be developed. Charts I through III show such patterns for individual shots. The Teapot report contains a similar map which shows the cumulative fallout for the entire Teapot series and a tabulation of doses calculated in two ways for populated places in the area.[1]

To supplement these data calculated from meter readings, use was made of film badges.[1] Film-badge stations consisted of the following categories: 171 worn by residents in the off-site area; 106 posted in populated areas; 152 inside and outside schools; and 126 at nonpopulated points in the off-site area. Data from these film badges is contained in the Teapot report. In general they agree favorably with computed data and have the advantage of comprising a permanent record of exposures.

A comparison of the data from the film badges indicate that the dosage received by inhabitants in a particular area is less than the dose indicated for that area as measured by the same method. Approximately 94 percent of the dosages measured on people were within the 0 to 100 mr. range while only about 57 percent of the film badges posted in the populated areas indicated exposures below 100 mr.[1]

The use of film badges, particularly on individuals, is being expanded during Operation Plumbbob. We are also supplementing monitoring instrument readings and film badges with recording instruments that will give us a continuous record of gamma radiation levels in a number of the populated areas.

Data on local fallout obtained by the Public Health Service during any Pacific test series is much more limited than is the case in Nevada. During Operation Redwing the Service had personnel on the populated atolls of Utirik, Ujelang, and Wotho adjacent to the Pacific Proving Grounds to maintain a record of radiation levels and initiate any necessary action to minimize exposure of the natives to radiation.[2] Data was also obtained from a weather station on Rongarik Atoll and at JTF7 headquarters. Computed infinite doses from fallout due to Operation Redwing are as follows:

	Mr.
Ujelang Atoll	560
Utirik Atoll	50
Wotho Atoll	620
Rongarik Atoll	850

These figures are subject to the same qualifications as in the case of reported figures from Operation Teapot.

An attempt was made to supplement instrument readings on the populated atolls with film-badge data, but, due to technical difficulties which were not overcome until near the end of the operation, these data are incomplete and inconclusive.[3]

C. *Intermediate and delayed fallout*

Intermediate and delayed fallout are at concentrations and of ages to make them of little or no significance from the standpoint of acute external gamma exposure effects, but make them of relatively greater importance as internal beta emitters and with respect to the long-range biological effects. With the assistance of AEC, in 1956 and 1957, a routine system of sample collection and reporting in cooperation with State departments of health has been established. Our nationwide radiation surveillance network measures beta activity of particulates collected from air samples. Data from this network may be used to indicate the concentrations of radioactive materials which could expose humans to direct and indirect internal radiation hazards. Daily ambient gamma readings are also taken on a Geiger counter type of survey instrument.

[1] See footnote, p. 328.

[2] Unpublished report, Radiation Exposures Received on Populated Atoll as a Result of Operation Redwing.

[3] Unpublished report, Report on Experimental Film Badge Study During Operation Redwing.

Two references describe the collection and measurement of radioactivity deriving from the troposphere.[4 5] The Public Health Service, for a number of years, has been developing methods which assist the States in determining environmental radiation levels and interpreting those data in terms of Public Health significance.

Reference 4 summarizes the results of this operation and demonstrates the increasing amounts of fallout found in the United States from our, and foreign, nuclear tests. Reference 5 presents a more detailed study, principally in relation to rainfall, in the Cincinnati, Ohio, area.

Radioactivity in air, at any one location, is a daily variable and cannot quantitatively be predicted from a knowledge of test schedules. For public health evaluation there appears to be no substitute for routine measurement techniques. Deposition on the ground, to a large degree, is related to rainfall. Distribution of radioactivity, geographically, is then largely dependent upon local topography and meteorology. Rainfall may contain much more activity than do the surface waters which are fed by the rainfall. The protective factors offered by the watershed may give as high as 90 percent removal of gross radioactivity.

Fallout from many nuclear tests is now always present in the air we breathe and the water supplies for ourselves, our animals, and our plants. Since there are many variables it is necessary to make measurements and keep records on those factors in the environment which directly affect man in order to make a public health evaluation of the hazards.

VII. LOCAL FALLOUT: THE MECHANISMS BY WHICH IT CAN AFFECT MAN AND THE MEASURES HE CAN TAKE TO MINIMIZE EXPOSURE

B. Shelter and shielding and their effects

By the nature of the radiation involved, it has been observed that persons can protect themselves from the acute, external effects of the beta component of fallout simply by staying under cover at the time of fallout so that none or little falls on them. Virtually direct contact with the skin is necessary to produce beta burns. We have also observed that remaining in a building will provide some protection from gamma radiation as a result of the shielding effect of the structure and the distance from the fallout afforded by being in the building.

Some data on the gamma exposure protection afforded by this means was obtained during Operation Teapot by placing film badges inside and outside of school buildings.[1] A tabulation of the results is given in the Teapot report.

The significant feature of this data is the apparent protection offered by the school buildings. The upper exposure limit is reduced by a considerable factor on a gross basis and while about 95 percent of the inside exposures fall within the 0–100 mr range, only about 79 percent of the outside badges are below 100 mr.

During Operation Plumbbob the Service is going to attempt a much more complete documentation of the shielding effects of buildings. Film badges will be placed inside and outside of several different types of buildings and at several locations within the buildings. Film badge data will be supplemented insofar as possible with data from recording instruments which will give a continuous plot of time versus intensity of gamma radiation.

C. Other immediate emergency measures that can reduce hazard

The Public Health Service has operated under radsafe criteria in the Pacific and in Nevada which illustrate the type of emergency action which may be taken in the event of unexpectedly heavy fallout.[1 6] These were devolped jointly with JTF7 and the Nevada test organization respectively.

Both of these criteria recommend remaining indoors or under cover during periods of fallout to avoid direct contact with falling or settling radioactive particles. If exposed to fallout, personal decontamination is recommended including dusting and shaking off or laundering clothes and bathing with particular attention being given to washing under the arms, the groin, face, and hair. Covering of food and water to prevent ingestion of fallout particles is recommended.

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[4] A Brief Review of the Public Health Service Radiation Surveillance Network, May 22, 1957.

[5] The Distribution of Radioactivity From Rain, by L. R. Setter and C. P. Straub, presented at the American Geophysical Union Meeting, April 29–May 1, 1957, Washington, D. C.

[6] Radsafe Emergency Instructions for Populated Islands.

An emergency measure recommended in the Pacific is to stand in the lagoon immersed as far as possible in the water while continuing to wash off exposed portions of the body. This recommendation is based on the fact that the fallout settles from the surface and allows water to attenuate the radiations. This fact has been checked in the field by PHS personnel.

In extreme emergencies, evacuation of contaminated areas may be indicated. This procedure is practical only if the evacuation will result in lower exposures than would result by staying within a shelter and if the location and intensity of the fallout pattern is known so that persons will, in the least possible time, be moved to areas of lesser contamination rather than into an area of higher contamination.

D. Dose and dose-rate versus time

During Redwing the PHS collected data at intervals ranging from once daily to once each hour with a gamma survey instrument at each of the atolls of concern.[2]

This data shows a phenomenon that has not, to our knowledge, been discussed to any great extent and that is the fact that, in the case of the larger weapons, the arrival of fallout may be extended over a period of several hours. Thus, although the fission products are decaying, this not apparent because of the continued arrival of new fallout. Typically, the radiation intensity will build up quite rapidly to a maximum, remain at or near this maximum for a period of several hours, and then start to decrease slowly. Thus a significant amount of exposure may be received before apparent decay starts.

VIII. DELAYED FALLOUT

A. The relative importance of internal emitters compared with external radiation in general for the long-run fallout situation

Elsewhere in our presentation mention has been made of the Public Health Service surveillance programs for air, water and milk. From the data which the Service has collected, and from other published information, we are following the obvious conclusion that, especially in relation to fallout, we must develop the trends of the amounts of internal emitters in man's environment and in his food chain. Because of the masking effect of natural background, external exposure effects relatable to fallout appear to be small in long-term potential when compared to the probabilities of accumulative buildup of internal emitters.

B. Deposition on and migration in soil and transport by surface waters

A number of Public Health Service studies are directly associated with the problems of migration and transport. Specific reference is made to the cooperative studies on high level radioactive waste performed by our staff from the Robert A. Taft Sanitary Enigineering Center at Oak Ridge National Laboratory.[7]

In relation to the problem of transport in surface waters, background and operational studies made by the PHS at the Columbia and Savannah River systems have a direct bearing, and provide research support data.[8, 9]

D. The effect of fallout on water supplies for human, agricultural, and industrial use

The Public Health Service has studied efficiency of normal water-treatment methods for the removal of radioisotopes from water supplies, and has made observations on the natural protective mechanisms.[10]

Depending, of course, on the exact nature of the radioactive compounds water-treatment methods offer limited protection. The degree of protection is on the order of 10 percent to 98 percent removal, or a decontamination factor ranging from 1.1 to 50.

The protective factors found in nature such as removal in watershed areas, are also within this range.[5] We have observed that in order to achieve removals of a much higher degree, as might prove necessary in the event of massive fallout during time of war or nuclear accident, the potential cost of effective water

[7] ORNL 1684, Radioactive Waste Disposal Research, by R. J. Morton et al., sec. I–60, Health Physics Division Semiannual Program Report, for period ending January 31, 1954.

[8] Columbia River Studies.

[9] Interim Report on the Savannah River Studies, July 1951–July 1952. U. S. Department of HEW, Public Health Service, 1954.

[10] Limitations of Water Treatment Methods for Removing Radioactive Contaminants, by C. P. Straub, Public Health Reports, No. 70, 897 (1955).

treatment, such as ion exchange removal, increases tremendously. The requirements in treatment materials in quantity alone is probably prohibitive. At the present time we cannot state that modern water-treatment methods applicable to the general population offer substantial protection against fallout.

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5. The Distribution of Radioactivity From Rain, by L. R. Setter and C. P. Straub, presented at the American Geophysical Union meeting, April 29–May 1, 1957, Washington, D. C. (See p. 466.)
6. Radsafe Emergency Instructions for Populated Islands, JTF-7. (See p. 475.)
7. ORNL 1684, Radioactive Waste Disposal Research, by R. J. Morton, et al., section I-60, Health Physics Division semiannual progress report for period ending January 31, 1954.
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12. Measurement of Low-Level Radioactivity in Water, by L. R. Setter and A. S. Goldin, Journal American Water Works Association, volume 48, No. 11, November 1956.
13. Unpublished office memo on Measurement of Radioactivity in Water, Bottom Silts, and Biological Materials, by J. E. Flanagan, Jr., January 30, 1957.

Report of Off-Site Radiological Safety Activities—Operation Teapot, Nevada Test Site, Spring, 1955

Prepared for the Test Division, Santa Fe Operations Office, United States Atomic Energy Commission; prepared by J. B. Sanders, Branch Manager, Las Vegas Branch Office, AEC; O. R. Placak, Off-Site Radiological Safety Officer, PHS; M. W. Carter, Deputy Off-Site Radiological Safety Officer, PHS

PURPOSE

The purpose of this report is to present a concise summary of off-site rad-safe activities during Operation Teapot and to serve as a source of information to interested AEC and health agency personnel. All pertinent data necessary to evaluate the exposure effects of the operation in populated areas are included. In the interests of brevity, selected data only are given for nonpopulated areas. Complete monitoring logs and detailed film badge results covering these areas are, however, available from the files of the Las Vegas Branch Office, AEC.

PLAN OF REPORT

This report is composed of the following general sections:
1. AEC radiological criteria for the protection of the public.
2. Off-site Rad-Safe Organization.
3. Methods and equipment used.
4. Public relations.
5. Résumé of individual shots are also included.

These individual sections cover the following materials: A summary of monitoring runs and dosages, airway closures, cloud tracking, and low-level terrain

surveys; a table which includes the dosages at all populated places where the external gamma dosage rate reading was greater than 0.1 mr/hr. and selected values in nonpopulated areas such as the maximum dosage and the dosage at points where the fallout crossed main highways; maps of fallout prediction, cloud tracking, low-level terrain survey, and ground-survey data.

6. Summaries.

In addition to the above, the following summaries and maps are included:

Integrated dosage for populated areas.
Film-badge data.
Milk-sampling data.
Water-sampling data.
Air-sampling data.
Maps: Integrated dosages from survey data.

1. AEC RADIOLOGICAL CRITERIA FOR THE PROTECTION OF THE PUBLIC

The Division of Biology and Medicine accepted the responsibility for establishing such criteria and procedures as were deemed necessary by the Atomic Energy Commission to protect the health and welfare of the general populace from the consequences of tests at the Nevada test site. The operational procedures adopted during Operation Teapot to meet these criteria were the responsibility of the Test Manager and were carried out by the Off-Site Rad-Safe Organization, under the direct supervision of the Support Director.

The basic criterion was that the whole-body gamma effective biological dose (EBD) for the off-site population should not exceed 3.9 roentgens over a period of 1 year. This total dose may result from a single exposure or a series of exposures.

The effective biological dose is an estimate of the biological damage dose taking into account the length of time for delivery of a given dose and the reduction of dose due to (*a*) shielding afforded by buildings, and (*b*) the process of weathering.

The EBD, as computed from integrations of dose rate readings, is the sum of three-fourths of the maximum theoretical radiation dose from time of fallout to 15 days later and one-half of the maximum theoretical dose from the 15th day to 1 year.

Values of gamma dose rate readings that will satisfy this criterion for particular situations are given in graphs I, II, and III.

Personnel should be requested to remain indoors with windows and doors closed when the gamma dose rate reading, measured by a survey meter held 3 feet above ground, reaches the values given in graph I at the times indicated.

Personnel decontamination should be practiced when the gamma dose rate readings, measured by a survey meter held 4 inches from the contaminated area, equals or exceeds the values given in graph II.

Vehicles should be cleaned inside and out when the gamma dose rate readings, measured by a survey meter held 4 inches from the surface, equals or exceeds the values given in graph III.

It is recommended that when the predicted fallout across a main highway will be equivalent to a 10 roentgen infinity gamma dose or higher, that vehicles will be held until after fallout has essentially ceased.

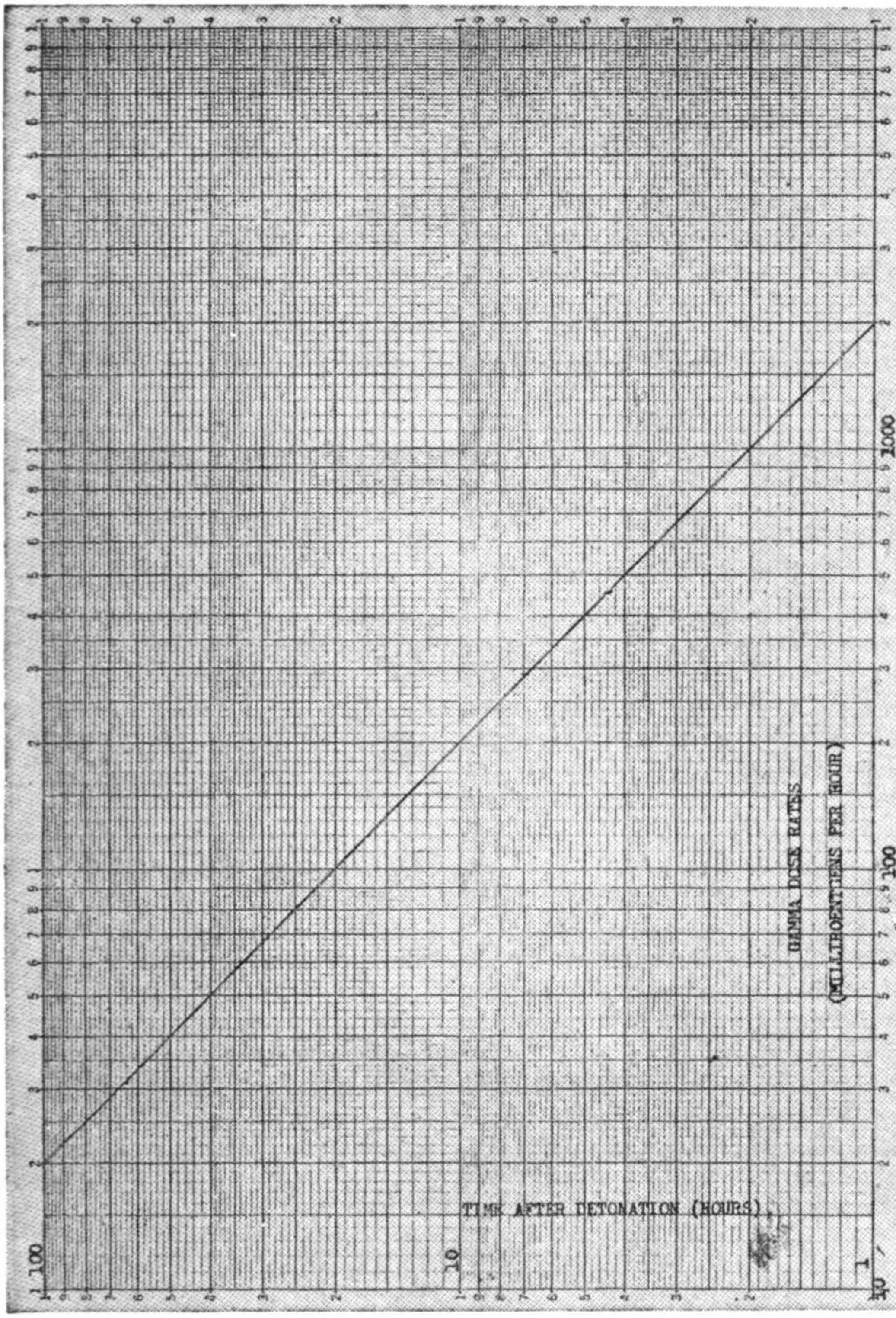
The above criteria do not apply to domestic or wild animals since levels of radiation which would be significant to them would have to be higher than those specified.

A more complete discussion of criteria is contained in a Division of Biology and Medicine, AEC, publication entitled "Atomic Energy Commission Radiological Safety Criteria and Procedures for Protecting the Public During Weapons Testing at the Nevada Test Site" dated February 1955.

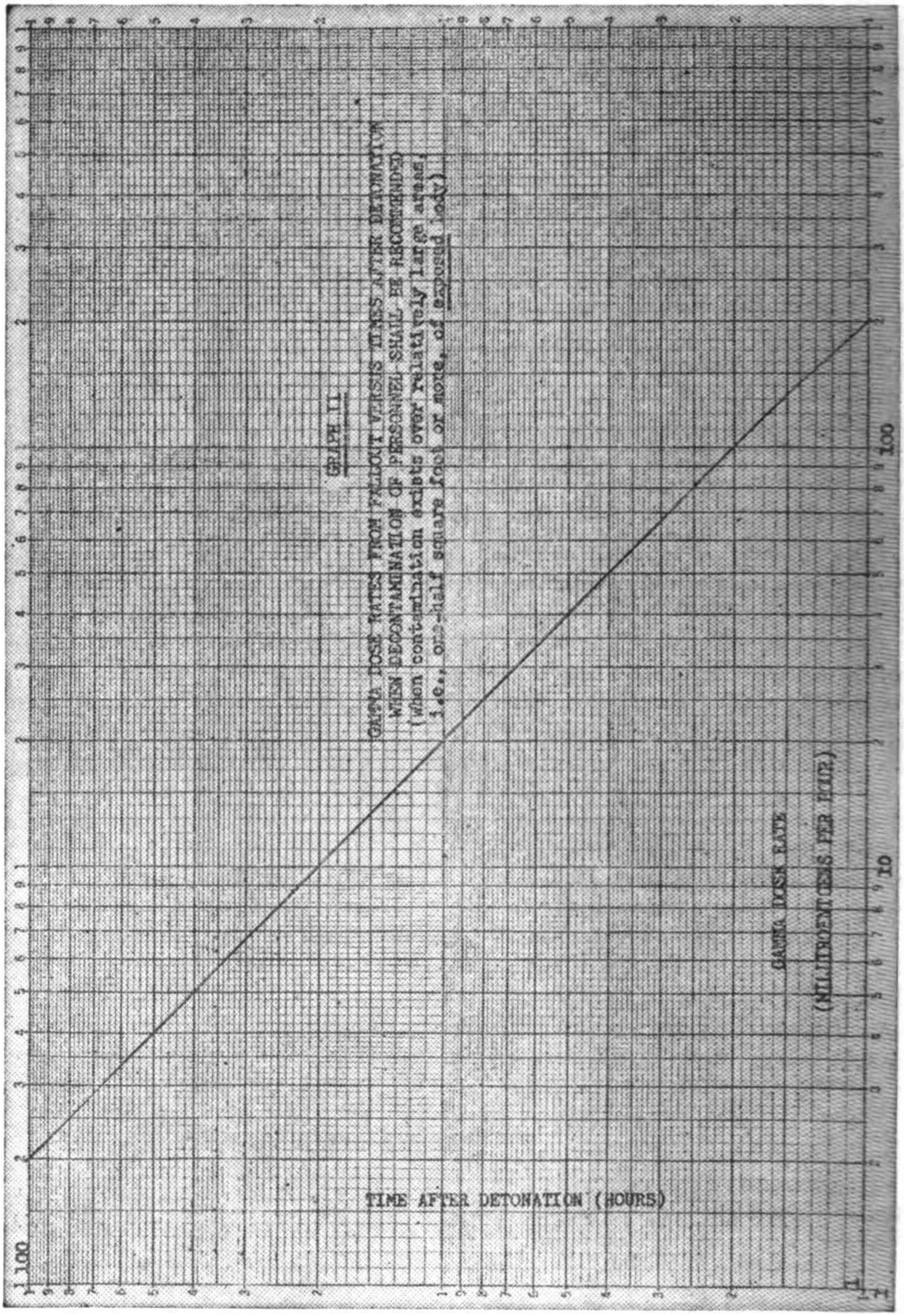
2. OFF-SITE RAD SAFE ORGANIZATION

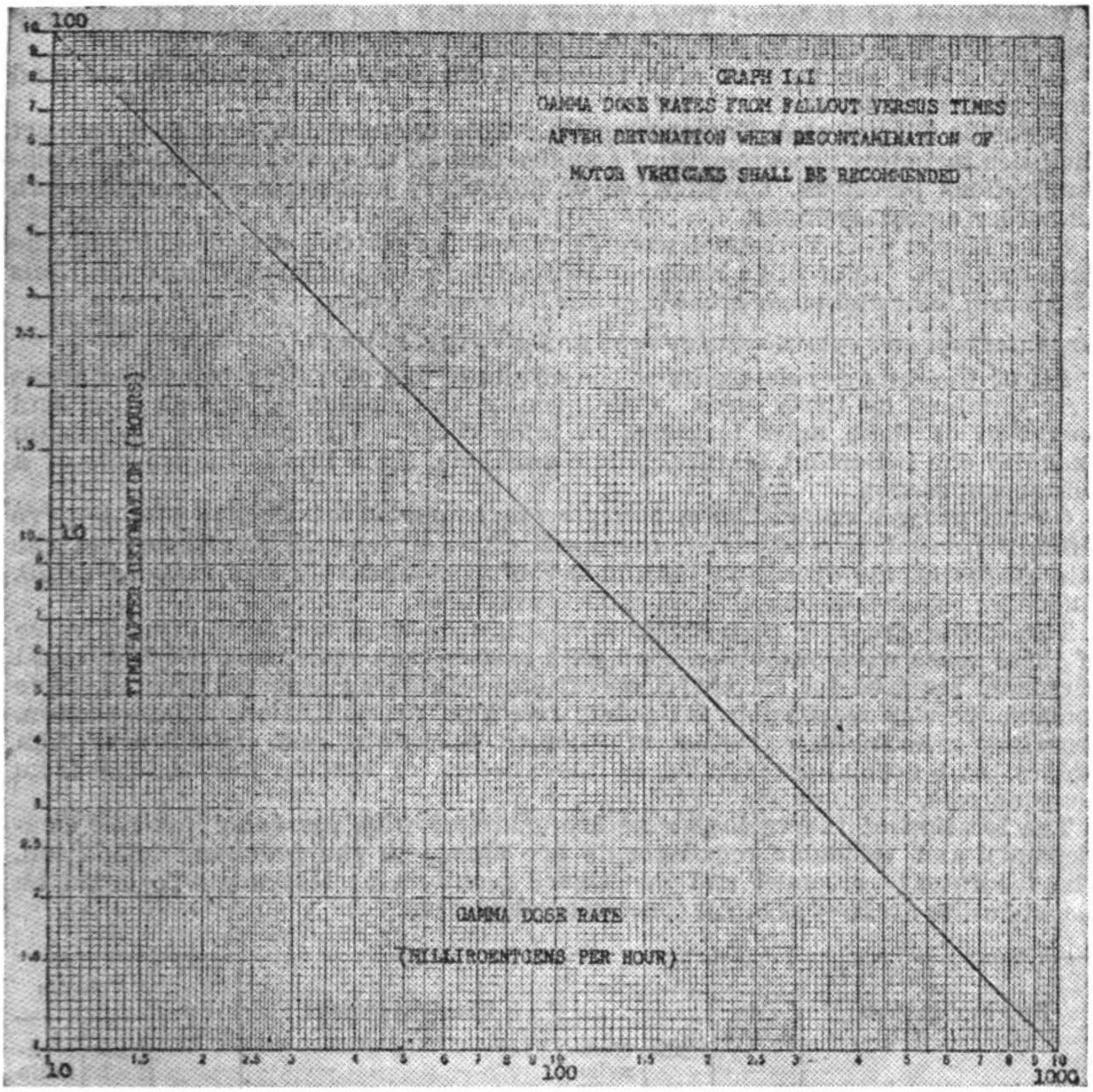
Off-site rad safe operations were a responsibility of the Test Manager and the Support Director, and were directed by the Deputy Director for Support, who was the Off-Site Operations Chief, and the PHS officer in charge, who was the Deputy Off-Site Operations Chief.

The various functions of the Off-Site program as outlined in the scope of work immediately following were carried out by personnel from the AEC, PHS, DOD, Reynolds Electrical and Engineering Co., and Silas-Mason Co.



GRAPH I
GAMMA DOSE RATES FROM FALLOUT VERSUS TIMES AFTER DETONATION WHEN PERSONNEL SHALL BE ADVISED TO REMAIN INDOORS


GRAPH 11
GAMMA DOSE RATES FROM FALLOUT VERSUS TIMES AFTER DETONATION
WHEN DECONTAMINATION OF PERSONNEL SHALL BE RECOMMENDED
(when contamination exists over relatively large areas,
i.e., one-half square foot or more, of exposed body)
GAMMA DOSE RATE
(MILLIROENTGENS PER HOUR)
TIME AFTER DETONATION (HOURS)
100
10
1



Scope of program

The off-site rad safe program dated January 10, 1955, was designed to accomplish the following objectives:

1. To accurately delineate the duration and extent of the fallout pattern as determined by ground surveys.
2. To verify the above by low-level terrain surveys using aerial monitoring.
3. To determine, by aerial tracking, the intensity and direction of the radioactive cloud.
4. To determine the actual exposures to people and livestock, by the above methods, by film-badge exposure records and by air, milk, and water samples.
5. To obtain data, at points close to the Nevada Test Site, to improve the formulae used in fallout prediction.
6. To conduct a continuing public relations and education program.
7. To record, map, and report the data obtained.

Responsibilities of various agencies

Atomic Energy Commission: The AEC was responsible for the overall administration of the program and of the work of other agencies outlined in more detail below. This includes policy decisions, budget requirements, procurement of materials and supplies, and all other support requirements.

Public Health Service: All ground monitoring crews were composed of regular and reserve PHS personnel with the exceptions noted under Silas Mason Co. and Los Alamos Scientific Laboratory employees W. S. Johnson and C. P. Skillern, who assisted in prior planning and during the first five shots.

This group was directly responsible for accomplishing the objectives set forth in items 1, 4, 5, 6, and 7.

Department of Defense: This agency supplied and maintained the survey instruments used and also supplied and processed all film badges.

Additionally, air support was furnished for low-level terrain survey and cloud-tracking purposes.

Reynolds Electrical & Engineering Co.: This organization furnished support facilities including procurement of supplies and services, stenographic and communications personnel, maintenance of laboratory and automotive equipment, and other necessary items.

Silas Mason Co.: Personnel were furnished for plotting and mapping of the data obtained. Four Silas Mason employees were used in monitoring operations at Lincoln mine and other areas near the Nevada test site.

Organization and operation of ground and air support units

All of the data for determining the effects of the operation in off-site areas were obtained by these units. Consequently, the method of organization and operation of these units is given, in some detail. The following discussion excludes one important feature, public relations, since this is the subject of a subsequent section.

Offsite ground units: These teams were composed of regular and reserve USPHS personnel. Originally, there were 33 positions filled, although in the late stages of the operation the number of men available was reduced to 20. Including replacements, a total of 66 men were used.

The offsite rad safe plan established areas of local responsibility. Twelve of these zones were organized, each with a zone commander and the additional personnel required for successful operation. Within an assigned area the zone commander was responsible for public relations, dissemination of information, reporting grievances, collection of samples, placement and collection of film badges, and normal monitoring in the absence of specific instructions from headquarters.

The location of the various zone headquarters with personnel (at full complement) and vehicular requirements are shown in the following tabulation. The laboratory personnel and unassigned monitors at Mercury who could be dispatched to areas of greatest concern are indicated.

Zone headquarters	Personnel	Vehicles		Zone headquarters	Personnel	Vehicles	
		Radio	Nonradio			Radio	Nonradio
1. Tonopah, Nev.	2	1	------	9. Caliente, Nev.	2	1	------
2. Mercury, Nev.	1	1	------	10. Pioche, Nev.	2	1	------
3. Las Vegas, Nev.	1	1	------	11. Ely, Nev.	3	1	1
4. Glendale, Nev.	2	1	------	Eureka, Nev.	1	1	------
Mesquite, Nev.	1	1	------	12. Lincoln mine (Tempiute), Nev.	2	1	1
5. St. George, Utah	2	1	------	Headquarters	4	1	------
6. Cedar City, Utah	2	1	------	Unassigned monitors at headquarters	4	4	------
7. Beaver, Utah	2	1	------				
8. Alamo, Nev.	2	1	------				

A complete roster of all off-site personnel is contained in appendix I.

Off-site communications were maintained by telephone and radio, telephones being used only when the radio network was not operating. This dual system of communications operated well and satisfactory contact with field personnel was maintained.

The radio net was composed of a net control station at Mercury, fixed and semifixed relay stations and mobile receiving and transmitting sets in the monitoring vehicles. The semifixed stations were mounted in trailers and could be relocated as required by a particular operation. The normal period of operation was from 0800 to 1600 each day. Operation subsequent to a shot was continuous until the all-clear announcement by net control.

The type, normal location, and personnel of the radio net at the start of the operation are given in the following tabulation.

Type station	Base station	Number of personnel
Control station	Mercury, Nev	2
Fixed	Currant, Nev	2
Do	St. George, Utah	2
Do	Lincoln Mine, Nev	2
Semifixed	Sunnyside or Warm Springs, Nev	1
Do	Glendale, Nev	2
Do	Alamo, Nev	2
Do	Caliente, Nev	2
Do	Pioche, Nev	2
Do	Ely, Nev	2
Do	Eureka or Geyser, Nev	2

A normal abbreviated sequence of events for ground monitoring operations follows:

Preshot:
1. Decision to proceed tentatively at evening weather briefing.
2. Field stations alerted—background samples started.
3. Radio stations and unassigned monitors dispatched as required.
4. Decision to proceed confirmed at early morning briefing.
5. Additional monitors dispatched as required.
6. Special preparations made, such as for roadblocks and evacuation.
7. Monitors advise people in their area.

Postshot:
8. All roads and populated areas in fallout area monitored as directed by headquarters.
9. All other monitors operate in manner prescribed in general instructions.
10. Monitoring of roads discontinued when no further information can be obtained.

D+1 following day:
11. Remonitoring performed as required.
12. Air samples, milk and water samples were collected as required.
13. Samples and data dispatched to laboratory for processing and counting.
14. Film badges collected as directed by headquarters.
15. Complaints and grievances investigated.
16. Field men contінle public relations program.
17. Headquarters prepares report of the operation.

Off-site air support unit: This unit was staffed by Air Force personnel and including replacements was composed of approximately 20 airmen. The mission of the unit was:

1. To make low-level terrain surveys along the path of the fallout following a shot, and preshot reconnaissance surveys to check isolated areas for persons or animals.
2. To track the radioactive cloud or clouds at various altitudes and to record and plot the data obtained.
3. To assist the CAA in directing closure of airways in which a radiation hazard might develop based on preshot predictions and to recommend necessary changes based on actual cloud-tracking operation following a shot.

The aircraft assigned to the unit and their functional use are tabulated below. The detection devices used were T-1B and MX-5 type instruments. The air-to-ground conversion curve is shown as graph IV.

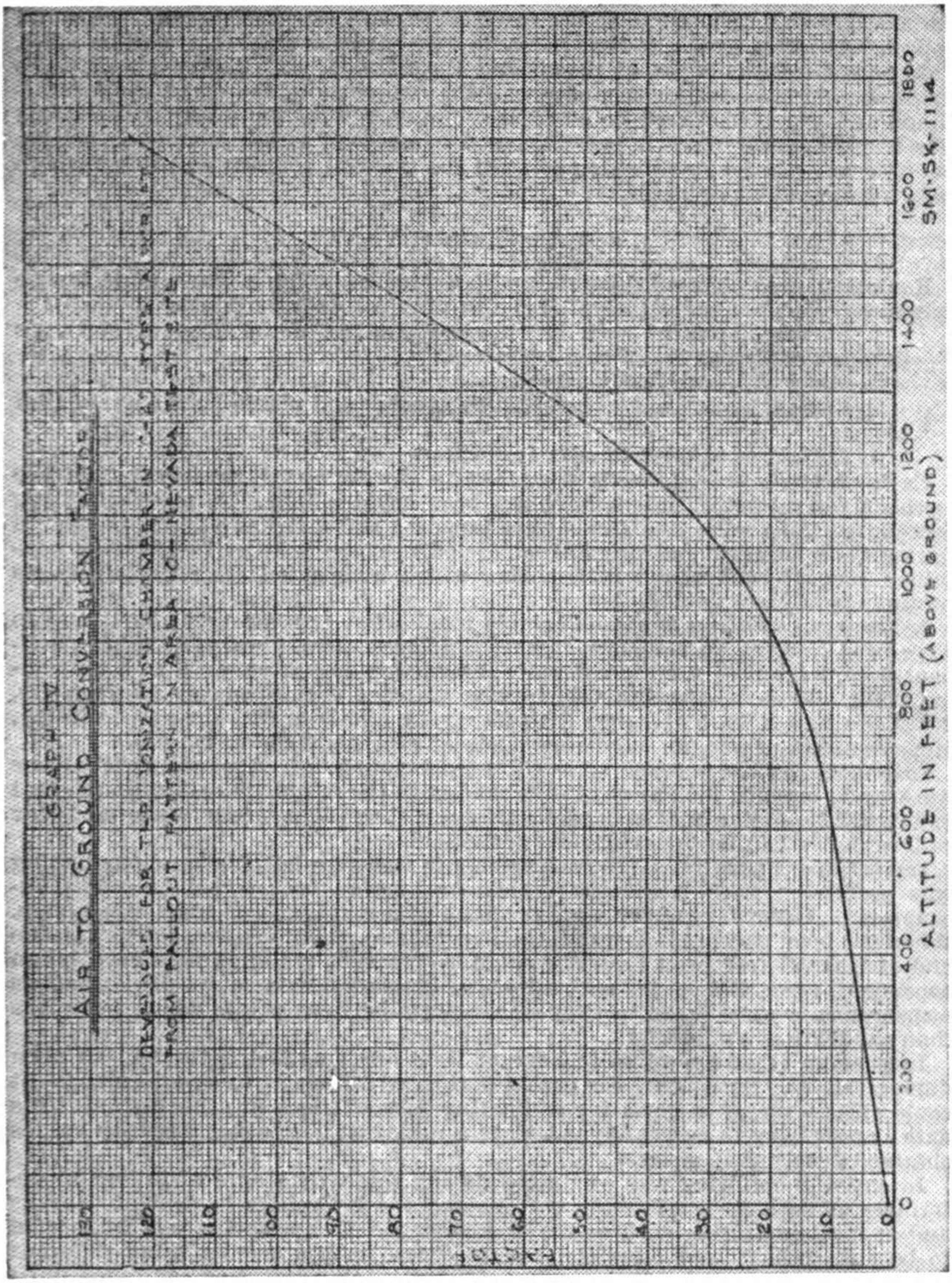
Type of aircraft	Number available	Use
C-47	2	Low level terrain surveys at 200 to 600 eet.
B-25	1	Cloud tracking, 10,000 to 15,000 feet.
B-29	1	Cloud tracking, 20,000 to 25,000 feet.
B-50	1	Cloud tracking, 27,000 to 32,000 feet.

A brief résumé of the technique of low level terrain survey and cloud tracking operations follows:

Low level terrain survey

Prior to the initial shot a terrain survey was conducted on D-1 for the purpose of locating persons and/or animals in the vicinity of the test site. On subsequent shots, the D-1 survey was conducted only upon request of the offsite operations chief or when reports indicated new concentrations or considerable changes in known livestock locations. Information was kept current by noting such positions whenever a low level survey of any type was flown.

On shot day, after sufficient time had been allowed for the fallout to occur, a low level mission was flown to delineate the fallout zones. To accomplish this mission, the aircraft was initially maneuvered to a point near ground zero to cross the suspected fallout zone at an angle of about 90°. From this starting point the fallout path was repeatedly crossed at altitude varying from 200 to 600 feet above the terrain, the interval between successive crossings varying from 3 to 10 miles, depending on the local terrain features. If possible, an altitude of about 300 to 500 feet above the terrain was maintained, since these proved to be the best operating levels for accurate readings on the radio altimeter. Since the conversion of the air reading of the radiac meter to a corresponding surface reading is dependent upon the altitude of the aircraft above the terrain, it was necessary that this factor be known as accurately as possible. In converting these readings, correlation curve (graph IV) was used. This curve was plotted from data obtained by flying a C-47 at various known altitudes above areas with known radiation intensities. The correlation between readings obtained by air surveys and those obtained by ground monitors was in reasonable agreement throughout the operation. The aerial survey proved invaluable in obtaining data in regions inaccessible to ground parties, thereby making it possible to more completely determine the actual fallout patterns.


GRAPH IV
AIR TO GROUND CONVERSION FACTOR
ALTITUDE IN FEET (ABOVE GROUND)
SM-SK-1114
0
200
400
600
800
1000
1200
1400
1600
1800
0
10
20
30
40
50
60
70
80
90
100
110
120
130

Cloud tracking

In order that the tracking aircraft could avoid deep penetrations of the cloud, the cloud was approached from one side at an angle of approximately 30° until a reading of 10 mr/hr or higher was obtained on the radiac meter. At this point the aircraft was turned out of the cloud as sharply as possible, and the cloud approached again at a different point, in this case the suspected leading edge. This procedure was repeated throughout the mission, with the result that the successive positions of leading edge and the two sides of the cloud were determined and provided a definite cloud track when plotted on a map. The cloud was tracked either until it had dispersed to such an extent that it no longer followed any particular direction or until the tracking aircraft had to return to base for operational reasons.

3. EQUIPMENT AND METHODS

Equipment was selected, located, and operated in such a manner as to insure maximum effectiveness in the collection of physical data pertaining to:

1. Surface levels of activity (normally, 3 feet above ground level), as determined by the use of survey meters.
2. Concentration of airborne activity.
3. External gamma dose received by persons and places by the use of film badges.
4. Activity contained in milk and water.

Each of these procedures is described in the following paragraphs, as the methods for sampling fallout have not been standardized. Detailed operating procedures along with data forms were prepared and distributed to all personnel during their briefing and orientation period. These written instructions contained general background information which augmented their usefulness as routine operational guides.

1. Surface radiation levels.—Portable monitoring (survey type) instruments were used to measure radiation intensity. These rates, along with other pertinent data, were then used to calculate the gamma dosage received at a particular point. Each monitoring vehicle was supplied with 4 survey instruments, 2 MX–5's and 2 T1–b's (range 0 to 20 mr/hr and 0 to 50 r/hr respectively). Measurements of gamma only were made at hip height above terrain.

Instruments were checked and calibrated before issue. Periodic calibrations were made on each instrument in the field with the minimum calibration period being before and after each detonation. Cobalt 60 sources were used for calibration both at headquarters and in the field.

During monitoring runs, the instruments in use were left "on" and monitoring was performed from inside the vehicle as long as background only was encountered. General readings were recorded at a maximum of 10-mile intervals. When the level encountered was twice background, monitoring was done outside and at least 25 feet from the vehicle. More frequent readings were then taken dependent upon the levels encountered. Distances were quite important as measurements were found to vary significantly between points which were less than one-tenth of a mile apart.

In general, it was possible to have at least one monitoring team in an area during fallout. Such being the case, the time of fallout at this particular point could then serve as a basis for estimating fallout times in other areas. This data is necessary to accurately calculate a radiation dose using intensity values obtained from survey meters.

Intensive monitoring was conducted during the early stages of fallout to determine as soon as possible the pattern and the intensities in populated areas and at strategic places such as major highways. Remonitoring was performed to be sure fallout was complete, and to obtain measurements using different instruments operated by different individuals. Monitoring was continued until it was thought no further useful data could be collected or because another detonation was imminently scheduled. It was necessary in a few instances to compromise slightly between completing today's shot activities and preparation for tomorrow's shot.

2. Airborne concentrations.—Staplex high volume air samplers were used with an MSA comfo-all dust filter for the collection of airborne contaminants. The rate of flow was in the range 1.1 to 1.3 cubic meters per minute. The standard sampling period was 28 hours beginning at shot time. Background samples, however, were run prior to each shot. The 28-hour sampling period included 7

filter changes ranging from time periods of 1 to 16 hours. More frequent changes were made when fallout occurred or when the flow rate decreased appreciably.

All filter samples were returned to the laboratory for gross beta counting. Proportional counters in conjunction with Sr–90+Y–90 standards were used for laboratory counting. For purposes of calculation, activity measured was extrapolated to midcollection time. The method of calculation resulted in a visual presentation of fallout pattern and distribution. Air activity concentrations were finally expressed as total microcuries per cubic meter of air averaged over the sampling period.

Approximately 230 individual filter samples were collected and counted following each detonation.

3. *Film badges.*—DuPont film packet type 559 film badges, consisting of two film components (type 502 and type 606), were used. The badges were placed in communities, along highways at 10- to 15-mile intervals, in strategic desert locations, on representative people in various towns and ranches, and in all known schools in the off-site area with the exception of the Las Vegas school system. At schools, badges were placed inside the building, outside, and usually on at least one member of the faculty.

Personnel badges were clipped on, while the "area" badges were mounted with either masking tape or placed in glassine envelopes which were tacked to a post, tree, or building. Of course, the badges themselves were sheathed in a watertight plastic envelope.

Badges were changed at frequent intervals. The collected badges were returned to the laboratory and the dosage calculated by comparing their net optical density to that if similar film packets exposed to a CO–60 standard.

Approximately 600 film badges (per change) were in place at the various stations before, during, and following the test series. Using this procedure, data are available on background; incremental additions of activity; overall exposure during the time period covered; the effect of certain structures on reducing gamma radiation; and, by comparison with dosages calculated from monitoring readings, the effectiveness of survey meters for obtaining information from which dosages are calculated.

4. *Activity contained in milk and water.*—Milk samples were collected from selected herds in each zone, from retail stores, from all processing plants in the off-site area, and any herd which was thought to be affected by fallout. Such a program should reveal the maximum activity contained in milk as well as the average levels to which the general population would be exposed. Samples were collected periodically with enough flexibility in sampling to insure adequate samples to define any given situation.

Water samples were collected from surface and subsurface water supplies, irrigation canals, and stock-watering ponds. Specific sampling stations were established and sampled routinely. Here again, samples were taken from any watering point which could possibly be affected by fallout.

The first sets of water and milk samples were collected prior to the start of the series. After assay, these data were used as the normal background radiation level. It could then be determined if the series produced contamination and the magnitude of such contamination.

Milk and water samples were sent to the laboratory for assay. Yet ashing, using nitric acid and hydrogen peroxide, was the method of sample preparation. Residues were transferred to counting dishes; a wetting agent added; dried under infrared lamps; and counted in proportional counters. Sr–90+Y–90 standards were used. The results are presented as microcuries per milliliter at the time of collection and/or the time of fallout.

5. *Personnel monitoring.*—Every person actively engaged in the off-site program was supplied with Du Pont type 559 film packet and a 1 roentgen Cambridge dosimeter. The dosage recorded by the film badge was used as the official record exposure, as required by the test manager. The dosimeter was to be used for information of use to the individual and not as a part of the official record.

b. Laboratory equipment.—Laboratory equipment consisted of four proportional counters which were fed methane gas. Three were connected to count rate meters and Esterline-Angus recorders while the fourth was connected to a decade scaler. The probes and sample housings were specifically designed to accommodate the type samples collected.

Two of the probes were used with a scanning device which enabled the counting of up to 100 micocuries on a single sample. These arrangements were used on the more active air samples.

All laboratory counting equipment was designed and built by the instruments division of the Los Alamos Scientific Laboratory in Los Alamos, N. Mex.

4. PUBLIC RELATIONS

It was recognized that adequate public relations is necessary to the successful operation of the Nevada test site. The off-site program was designed to facilitate good public relations. This was accomplished by contacts and talks prior to the series, by the system of zone commanders who were largely responsible for good relations within a specified area, by following up each incident reported immediately and, of course, by the general program carried out by the Joint Office of Test Information.

The public relations program during the operation laid the general ground work for a continuing public relations program to be carried out in the interim periods.

In general, relations with the off-site populace were good. People were particularly appreciative of the fact that monitors were permanently stationed in their communities. Opinions expressed to monitors indicated that local populations felt more secure with this arrangement with regard to radiation hazards and that they appreciated having a local contact to go to for information or with complaints. Off-site personnel were able to carry out a continuous educational program since full advantage of their presence in the community was taken and they were asked to be on the programs of civic clubs and other organizations, to furnish material for radio programs and newspapers and to aid in school programs.

Prior arrangements.—Prior to the start of the series, all of the large population centers in the area were visited by off-site personnel to inform people of the forthcoming tests and the manner in which off-site problems would be handled.

Immediately before the start of the series most of these communities were revisited by a group consisting of the Test Manager, Scientific Advisor, Test Director, Support Director, Information Director, Off-Site Operations Chief, and the senior PHS officer. A series of talks were given in Caliente, Pioche, Ely, and Tonopah, Nev., and St. George and Salt Lake City, Utah. In these talks the value of continental nucler tests to the country was stressed and the precautionary measures to be taken with regard to public safety were outlined. People were informed of the plans to station monitors in their community and that these men were expected to become a part of the community during their stay and to be of service to it in regard to public safety, information or in any other way.

From 7 to 10 days before the initial detonation, the monitors with their equipment moved into the community, familiarized themselves with the area, made acquaintances and actively took over the job of public relations.

Liaison activities.—Arrangements were made to keep those health officials who might be primarily concerned, informed of the activities at the test site. The States normally involved were Nevada, Utah, California, and Arizona, and the State health officers of these States were advised routinely by phone of any fallout situation that might affect areas under their jurisdiction. The personnel advised in these instances were:

Nevada: Dr. Daniel J. Hurley, State health officer.
Utah: Dr. George A. Spendlove, State health officer.
California: Dr. John M. Heslep, designate of State health officer.
Arizona: Dr. C. G. Salsbury, State health officer.

In addition to these arrangements, contacts were made with affected USPHS officials and with local health officials.

Activities of zone personnel.—Zone personnel conducted a public-relations program on an informal and down-to-earth basis. They formed a wide acquaintance in their respective areas, participated in local events and took their instructions to become a part of the community seriously; as for example, the monitor at Glendale who became a Sunday school teacher, or the one in Alamo who plastered a ceiling in one of the hotel rooms. Such intimate association with the people in the area was good practical public relations, and while it may not have altered completely basic public opinion regarding the tests, it at least made the explanations of zone personnel more acceptable.

Every opportunity to reach the public through talks and film showings was accepted. Practically every person throughout the off-site area saw at least one film and listened to at least one discussion by monitors. This was accomplished through civic clubs, schools and PTA, and other groups. In this connection, it should be stated that the new film Atomic Tests in Nevada received enthusiastic reception. From the remarks made to zone personnel, it appears that general feeling was that, for the first time, the public was being shown exactly what happened during a shot.

A complete listing of public relations contacts is not available, but the partial list of film showings tabulated in table 1 will indicated the scope of this activity:

TABLE 1.—*Public relations—Movies*

Zone	Location	Date	Film	Attendance
Alamo	Alamo	Feb. 9	Target Nevada	100
	do	Feb. 10	Atoms in Agriculture (shown twice).	25
Caliente	Lincoln County High School.	May	Atomic Tests in Nevada, and Atoms in Agriculture.	200
	Elementary school	do	do	80
	Lincoln County High School.	do	Nuclear Reactors	30
	Elementary school (science and physics class).	May 12	do	38
Cedar City			Atomic Tests in Nevada.	1,180
			A Is for Atom	870
			Operation Ivy	36
			Target Nevada	36
Ely	Lions, Rotary, and chamber of commerce.	Feb. 9	Target Nevada, and A Is for Atom.	109
	Ely Woman's Club	Feb. 10	A Is for Atom	51
	Ely Elks' Club	do	do	30
	Roadrunners' Motorcycle Club.	Feb. 13	Operation Ivy, and A Is for Atom.	
Ely	Ely PTA	Feb. 14	Operation Ivy, and A Is for Atom.	75
	VFW and auxiliary	Feb. 17	do	50
	Ruth-Kimberly PTA	Feb. 21	Operation Ivy	40
	Society of Professional Engineers.	Feb. 22	do	20
	Steptoe Hospital staff	Feb. 25	do	
	Shut-ins	Feb. 26	Operation Ivy, and A Is for Atom.	14
	Fire department	Mar. 1	do	30
	Duckwater	Mar. 4	do	40
	Baker PTA	Mar. 5	do	60
	Eureka School	Mar. 11	A Is for Atom	70
	Austin School	Mar. 15	Operation Ivy	60
Glendale	Mesquite School	Apr. 7	A Is for Atom, and Target Nevada.	60
	Bunkerville School	Apr. 8	Target Nevada	105
	Overton School	Apr. 11	Target Nevada, and Atom Tests in Nevada.	175
	Mesquite Theatre	Apr. 15	do	150
	Overton High School	Apr. 21	A Is for Atom	40
	Overton Veterans' Club (attending: sportsmen, firemen, and California civil defense).	Apr. 25	Atomic Tests in Nevada, and Target Nevada.	88
Lincoln Mine	Lincoln Mine Theater	Apr. 24–30	Atomic Tests in Nevada.	500
Pioche	Pioche		A Is for Atom	20
	Volunteer fire department		do	
	Pioche		Operation Ivy	
	do		Operation Doorstep	
	Young women's literary club.		A Is for Atom	
	Latter-day Saints Church	Apr. 17	Atomic Tests in Nevada.	35
St. George	Glendale, Utah, PTA	Mar. 16	Target Nevada	35
	Kanab PTA	Apr. 4	Atomic Tests in Nevada.	45
	Kanab High School	Apr. 5	do	160
	Orderville PTA	Apr. 11	do	35
	St. George firemen	do	do	12
	Ladies' relief society Latter-day Saints.	do	do	200
	do	Apr. 12	do	40
	Elementary school	Apr. 13	do	230
	Dixie College	do	do	180
	VFW	do	Atomic Test in Nevada, and Target Nevada.	32

TABLE 1.—*Public relations—Movies*—Continued

Zone	Location	Date	Film	Attendance
St. George—Continued	Chamber of commerce	do	Atomic Tests in Nevada	40
	High school	Apr. 14	Atomic Tests in Nevada, and Target Nevada.	400
	Ladies' relief and faculty	Apr. 15	Atomic Tests in Nevada	60
	Lady Elks	do	do	35
	National Guard	Apr. 14	do	73
	Virgin PTA	Apr. 21	do	60
	Community church	Apr. 22	do	18
Tonopah	High school		Target Nevada (shown 3 times).	260
	Mizpah Hotel		Target Nevada	170
	Goldfield Elks	Feb. 28	do	60
	Fish Lake		do	50
	Manhattan	Feb. 23	do	60
	Round Mountain	Feb. 24	do	50
	Wellington Rotary		do	50
	Tonopah (2 clubs)		Atomic Energy	80
	Round Mountain		do	50
	Goldfield		do	60
	Wellington		do	50
Other:				
Beatty, Nev			Target Nevada, and Atomic Energy.	80
Do		Apr. 11	Atomic Tests in Nevada	60
Do	High school	Apr. 14-15	Atomic Tests in Nevada (shown twice).	175
Chattanooga, Tenn	Division of Health and Safety, TVA.	May 9	do	60
Fort Oglethorpe, Ga	Kiwanis Club	May 10	Atomic Tests in Nevada	25
Florence, Ala	Lions' Club	May 16	do	45
Los Angeles, Calif	ASCE. sanitary section	May 25	do	50
Total people seeing films.				[1] 7,550

[1] Not a full count. Conservative estimate made when attendance figure was missing.

In addition to these semiformal contacts, a large number of individual contacts were made. One interesting example of this indicates the public relations value of the film badge program. During a routine change of a personnel film badge in Goldfield, Nev., the wearer remarked that "there must be some fine people at the test site, since they were taking such precautions even in a small place like Goldfield." It must be recognized, however, that although relations throughout the off-site area were generally good, there are some specific areas of difficulty. An example of this is the attitude of the newspaper editor in Tonapah, who, contrary to editorial opinion in general, has maintained a highly critical attitude toward test activities.

Other informational material was distributed. The news releases of the Joint Office of Test Information were widely used by monitors. However, the most valuable piece of educational material was the little yellow booklet, Atomic Test Effects in the Nevada Test Site Region. Thousands of these were distributed through schools, post offices, motels, and by other means throughout southern Nevada and Utah, and in parts of Arizona and California. This was very well received. In fact, some people thought so highly of it that they requested copies to distribute on their own. Many of these booklets were picked up by tourists and were probably carried to all parts of the Nation.

Special investigations.—It was inevitable that numerous incidents requiring investigation should arise. These were of three types, as they effected material things, people, or livestock. All that came to the attention of the off-site program were investigated and are documented in the files.

With respect to material things, the greatest number of complaints were from prospectors. An explanation of the transient nature of radioactivity from fallout was generally acceptable. In all cases where blast damage was reported, forms for damage claims were mailed and these are being processed in the customary manner. In those cases where contamination from radiation were reported, such as on vehicles, the zone personnel investigated and were generally able to satisfy people during these visits that no hazard existed.

A number of cases of radiation damage to people were reported. These were investigated by the Cedar City Zone commander, Dr. Clinton G. Powell, who is a

PHS doctor. This procedure was so useful that it became apparent that it was a mistake to require medical personnel to also act as zone commanders. In any future operation, a qualified doctor with radiation experience should be available within the off-site program for the sole purpose of investigating claims of personal radiation injury.

Prior contacts were made with the local doctors. All investigations were made by working with local doctors. This procedure eliminated any chance of criticism about professional ethics, increased the patient's confidence in the procedure and did much to educate the local physicians in regard to radiation matters.

The general procedure was to have the patient brought to the local doctor's office. If necessary, off-site monitors provided the transportation. There both doctors examined the patient and arrived at a decision. Any costs were billed through Reynolds Electrical & Engineering, Inc.

In no case, of those examined, were there symptoms that could be definitely attributed to radiation injury. Many cases turned out to be some common ailment, diaper rash, in one case. However, the reports of eye irritation were so persistent that this matter should be investigated in order to prove or refute the widespread belief that this is due to test activities.

Reports of injury to livestock were reported by zone personnel and investigated during the series by veterinarians (Maj. Grant Kuhn and Col. Bernard Trum) from the AEC-University of Tennessee Agricultural Farm at Oak Ridge or by Dr. Wendell Brooksby, of the Utah State Agricultural College. There is little doubt that reputed livestock damage will continue to be reported for some time after the tests since livestock culture is such an important part of the economic life of the area. This suggests the desirability of the continuous services of a veterinarian with radiological training and of a sound investigative program.

5. RÉSUMÉ OF INDIVIDUAL SHOTS

This section includes a brief summary of results for each nuclear device detonated during the test series. While only condensed highlights are presented here, complete data are contained in the files of the Las Vegas branch office.

Each shot summary has been arranged, for ease of comparison, according to the outline below:

1. General information
2. Airway closure pattern
3. Cloud tracking
4. Low-level terrain survey
5. Ground monitoring results
6. Selected gamma dosages
7. Number of ground readings taken (above 0.1 mr./hr.)
8. Comparison of maps
9. Airborne radioactivity concentrations
10. Table—External gamma dose in populated areas and at selected nonpopulated points
11. Maps
    - (a) Prediction
    - (b) Cloud track
    - (c) Low-level terrain survey
    - (d) Ground monitoring
    - (e) Combined air and ground results

In some cases, all of the above maps are not available. For exemple, for certain shots it was not possible to obtain aerial results due to the extremely light fallout. On 1 occasion there were 2 detonations on the same day. In this case the results from the two individual detonations have been combined.

The maps are given in terms of infinite dose and/or effective biological dose.

Comparison of maps is done on an extremely gross basis. The major points of comparison are direction of fallout and relative magnitude of fallout, as determined from length of specific isodose contours.

Following the summary for Zucchini (the last shot of the series) is map 1 which represents the cumulative fallout plot for Operation Teapot. The map is plotted in terms of infinite dose and reflects both aerial and ground monitoring results.

For orientation purposes, as to the shot names, the times and dates of detonation, the type of detonation, and the firing area, the following tabulation is presented.

Devices detonated during Operation Teapot

Name	Detonated		Type	Area
	Time	Date		
Wasp	1200	Feb. 18	Airdrop	7—Yucca.
Moth	0545	Feb. 22	300-foot tower	3—Yucca.
Tesla	0530	Mar. 1	do	9—Yucca.
Turk	0520	Mar. 7	500-foot tower	2—Yucca.
Hornet	0520	Mar. 12	300-foot tower	3—Yucca.
Bee	0505	Mar. 22	500-foot tower	7—Yucca.
ESS	1230	Mar. 23	Subsurface	10—Yucca.
Apple	0455	Mar. 29	500-foot tower	4—Yucca.
Wasp Prime	1000	Mar. 29	Airdrop	7—Yucca.
HA	1000	Apr. 6	High altitude	Yucca.
Post	0430	Apr. 9	300-foot tower	9—Yucca.
MET	1115	Apr. 15	400-foot tower	Frenchman.
Apple II	0510	May 5	500-foot tower	1—Yucca.
Zucchini	0500	May 15	do	7—Yucca.

WASP

Wasp was an airdrop which was detonated at approximately 800 feet on February 18, 1955, at 12 noon. The shot took place in test area 7 in Yucca Flat.

The airway closure pattern was as follows:

1. A circular area around Yucca Flat, with a radius of 60 nautical miles, was ordered closed at all altitudes from 7:15 to 10 a. m.
2. A sector, bounded by radii at 100° and 210°, extending 175 and 120 nautical miles, respectively, from the end of the 210° radius extend due east to JF3015, then due north to intersection with 100° radius, was ordered closed from the surface to 30,000 feet from 8:45 to 11 a. m.
3. The following area was ordered closed from 10,000 feet to 30,000 feet from 11 a. m. to 5:30 p. m. From FF3030 due south to FE3000, then due east to ME0000, then follow Arizona-New Mexico border to 4 corners, then west to HH3000, then return to initial point.

Due to mechanical difficulty with the drop aircraft, the time of the shot was moved ahead, causing a corresponding shift of 4 hours in all closure times.

The cloud was tracked, as indicated on the accompanying map, from H plus 80 minutes to H plus 2 hours. In addition to reports from the B-25 tracker, reports from sampler aircraft were used to chart the cloud movement. Maximum cloud height observed was 20,000 feet. The cloud was tracked to a point southwest of Las Vegas (Goodsprings, Nev.), at which point it was so scattered as to become relatively undefined.

On D-1 day a low-level survey was made by one C-47 to locate and record the position of persons and/or animals in remote areas within the predicted fallout zone. On D-day the survey aircraft took off at approximately H plus 3 hours 45 minutes and reported no significant off-site contamination.

Ground-monitoring runs, which indicated activity substantially above background, were made along U. S. 95 between 10 miles east of Mercury Road and Indian Springs Air Force Base; on Nevada 52 between 12 miles south of U. S. 95 and the southern end of the highway; and along Nevada 85 from 22 to 32 miles southeast of Pahrump, Nev.

The maximum effective biological dose for populated area was 0.7 mr. at Cactus Springs, Nev. The maximum effective biological dose at a nonpopulated point was 55 mr. on Nevada 85, 28 miles southeast of Pahrump, Nev.

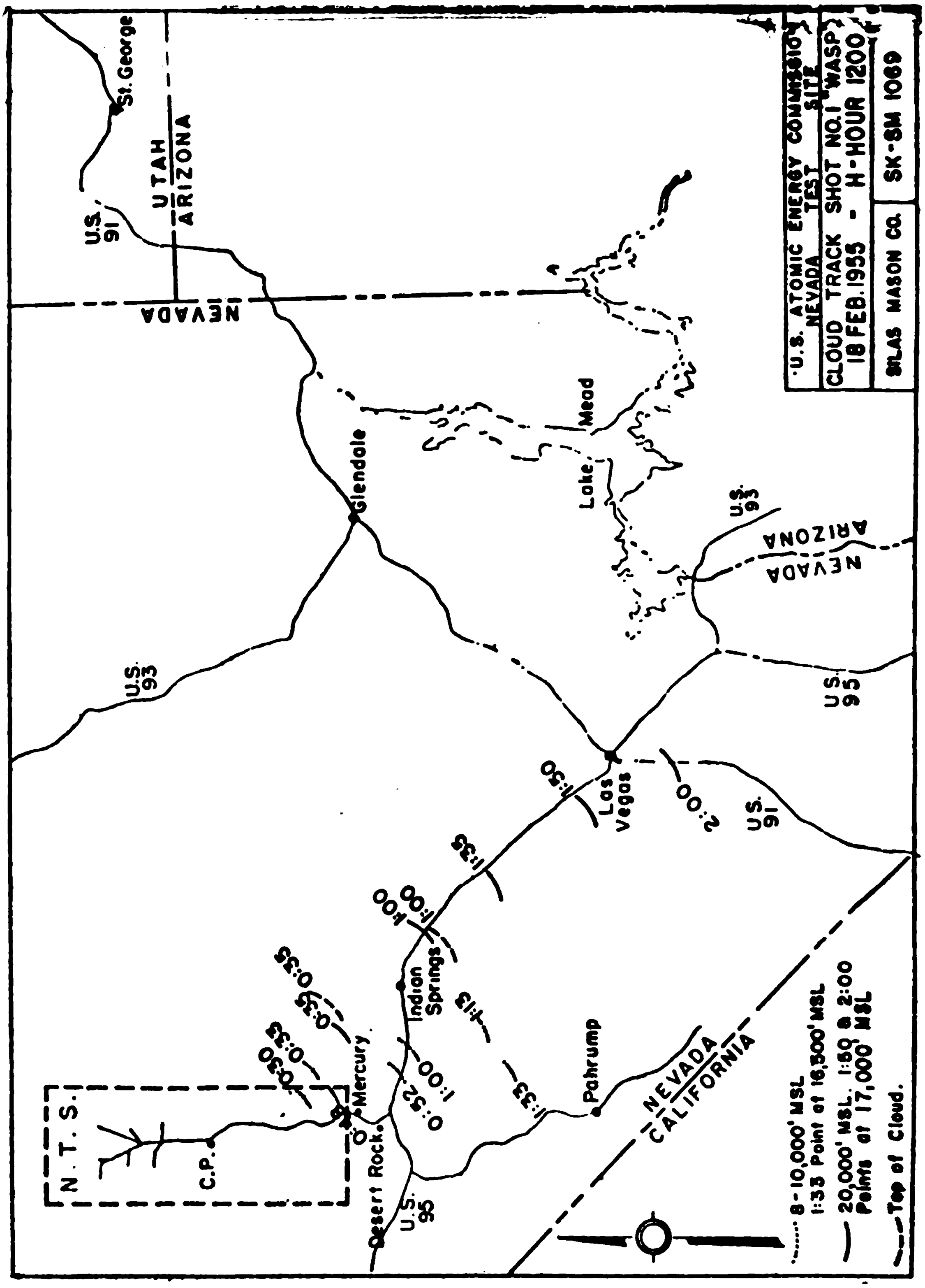
Only 10 individual monitoring readings above 0.1 mr./hr. were recorded.

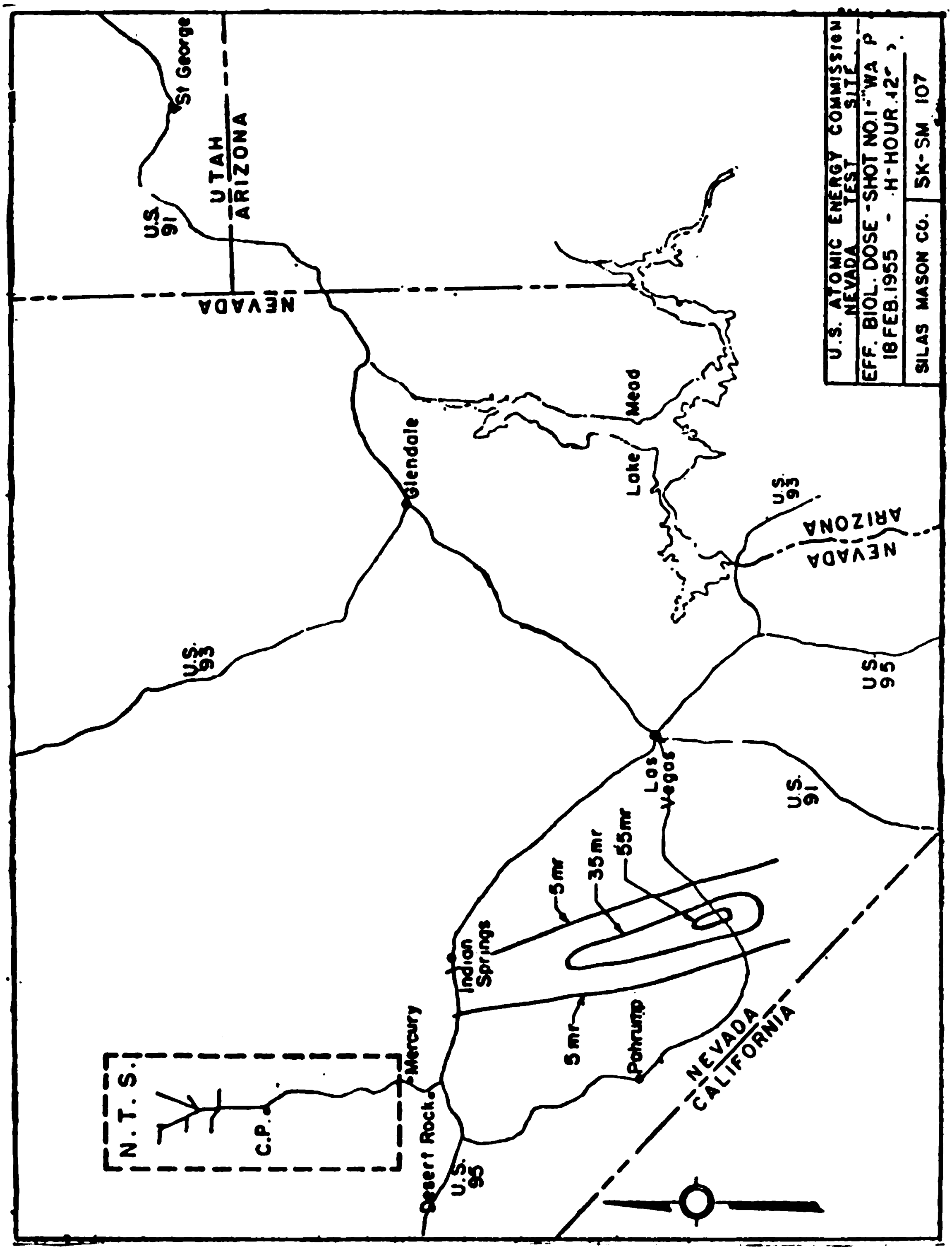
Fallout was very light as indicated by ground monitoring and also by the lack of data from the low-level terrain survey.

No air samples were collected which indicated an air activity concentration in excess of $10^{-4}\mu c/m^3$.

Wasp: External gamma dose in populated areas and at selected nonpopulated points

Location	Time of instrument reading (H plus hours)	Gamma ground level (mr./hr.)	Time of fallout (H plus hours)	Effective biological dose (mr.)	Infinite dose (mr.)
Populated areas:					
Indian Springs, Nev	1.6	0.1	1.0	0.5	0.8
Cactus Springs, Nev	1.9	.1	1.0	.7	1.2
Nonpopulated points:					
U. S. 95, 15 miles east of Mercury Road	1.7	1.5	1.0	8.4	14.0
Nevada 85, 28 miles southeast of Pahrump, Nev	3.6	5.5	3.0	55.0	110.0


U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
CLOUD TRACK SHOT NO. 1 "WASP"
18 FEB. 1955 - H-HOUR 1200
SILAS MASON CO.
SK-SM 1069
8-10,000' MSL
1:33 Point at 16,500' MSL
20,000' MSL. 1:50 & 2:00
Points at 17,000' MSL
Top of Cloud.
St. George
UTAH
ARIZONA
U.S. 91
NEVADA
Glendale
Lake Mead
U.S. 93
NEVADA
ARIZONA
U.S. 95
Las Vegas
U.S. 91
1:50
2:00
1:35
1:00
Indian Springs
1:13
Pahrump
1:33
NEVADA
CALIFORNIA
Mercury
Desert Rock
U.S. 95
N. T. S.
C.P.
0:35
0:33
0:30
0:52
1:00



U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
EFF. BIOL. DOSE - SHOT NO.1 "WASP"
18 FEB.1955 - H-HOUR.42
SILAS MASON CO.
SK-SM 107
St George
UTAH
ARIZONA
NEVADA
U.S. 91
Lake Mead
Glendale
U.S. 93
ARIZONA
NEVADA
U.S. 95
Los Vegas
U.S. 91
5mr
35mr
55mr
Indian Springs
Mercury
Pahrump
5mr
NEVADA
CALIFORNIA
N. T. S.
C.P.
Desert Rock
U.S. 95

Moth

Moth was a 300-foot tower detonation which was fired at 5:45 a. m. on February 22, 1955. The shot took place in test area 3 in Yucca Flat.

The airway closure pattern was as follows:

1. A circular area around Yucca Flat, with a radius of 60 nautical miles, was ordered closed at all altitudes from 5:15 to 8 a. m.
2. A sector bounded by radii at 120° and 180°, length of radius 125 nautical miles, was ordered closed from 15,000 to 26,000 feet between the hours of 6:45 and 8:15 a. m.
3. Finally, a large rectangular area, primarily in Arizona, was closed at the same altitudes as the above sector from 8 to 11:45 a. m. The boundaries of this area, as defined by Georef coordinates, were:

Continue the 120° radius to KE0030, then due south to Tucson, Ariz.

Continue the 180° radius to EE0050, then southeast to HC0000.

As the reports of the tracking aircraft came in, the following changes were made in the closure pattern:

At 6:30 a. m., the radius bounding the sector defined in (2) above was shifted from 120° to 90° out to KH0000, then due south to Tucson, Ariz.

At 6:45 a. m., the area south of the north edge of Airway Green 4 was opened at all altitudes.

At 6:48 a. m., all areas were opened to traffic at 24,000 feet and above.

The cloud was tracked, as indicated on the accompanying map, from H plus 18 minutes to H plus 3 hours 25 minutes. Reports from B–25 tracker and sampler aircraft were used. The maximum cloud height observed was 24,880 feet. The maximum height of the cloud decreased as it progressed on a general bearing of approximately 130°, stabilizing at roughly 22,000 feet. The path followed by the cloud took it north and east of Las Vegas, Nev., and extended for approximately 110 nautical miles when the tracking aircraft were recalled.

As an indication of the magnitude of radiation to be expected should a commercial aircraft penetrate the cloud, two F–84 aircraft were flown into the cloud and were checked for contamination upon return. The pertinent data are presented in the following tabulation:

	Aircraft No. 1	Aircraft No. 2
Time of penetration	H+3 hours	H+3 hours.
Duration in cloud	30 seconds	13 minutes.
Altitude	22,500 feet	20,000 feet.[1]
Maximum intensity	800 mr./hr	500 mr./hr.
Average intensity	300 mr./hr	400 mr./hr.
Time of landing	H+5 hours	H+5 hours.
Readings on various aircraft components:		
Drive brakes	100 mr./hr	480 mr./hr.
Wing tips	48 mr./hr	140 mr./hr.
Nose	50 mr./hr	180 mr./hr.
Impeller section of engine	100 mr./hr	480 mr./hr.
Pilot dose	30 mr	150 mr.

[1] Descending along cloud to 10,000 feet.

The low-level terrain survey was conducted by 1 C–47-type aircraft which took off at H plus 7 hours 45 minutes, completing the mission at H plus 10 hours. The contamination pattern disclosed by this survey is plotted on the accompanying map.

Monitoring runs, which indicated activity substantially above background, were made on the desert road running north from Indian Springs, Nev., along the desert road from Groom Road to Frenchman Flat; on the game preserve road running north from U. S. 95; on U. S. 93–91 in the vicinity of Dry Lake, Nev.; and along Nevada 40.

The maximum effective biological dose for a populated area was 130 mr. at Dry Lake, Nev. The maximum effective biological dose at a nonpopulated point was 5,900 mr. 22.8 miles north of Indian Springs, Nev., on a desert road.

Approximately 60 individual monitoring readings above 0.1 mr./hr. were recorded.

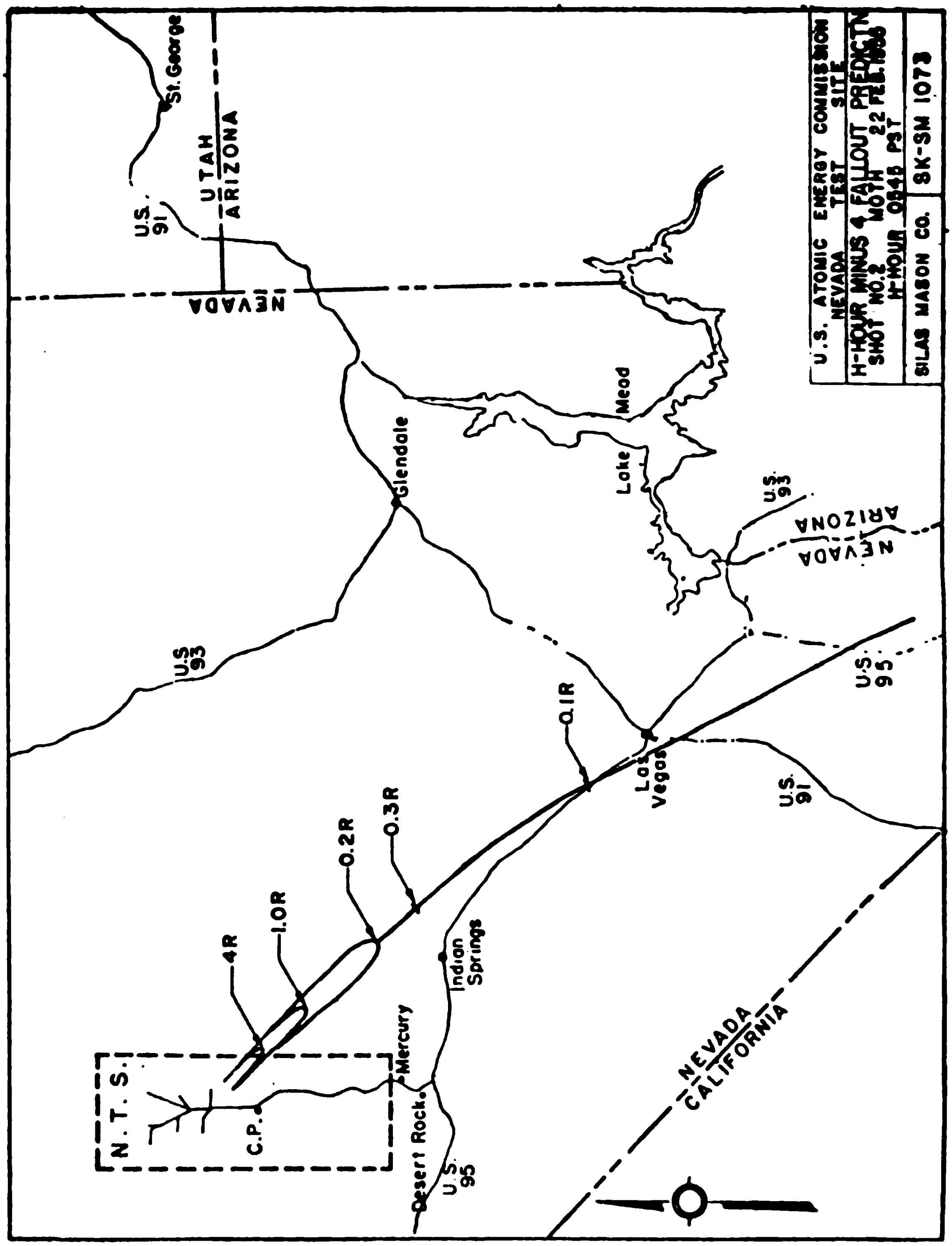
The H minus 4-hour prediction map indicated fairly good agreement with the factual maps. With very little shear in the fallout pattern, expected times of fallout could be readily predicted. The small amount of fallout to the northeast

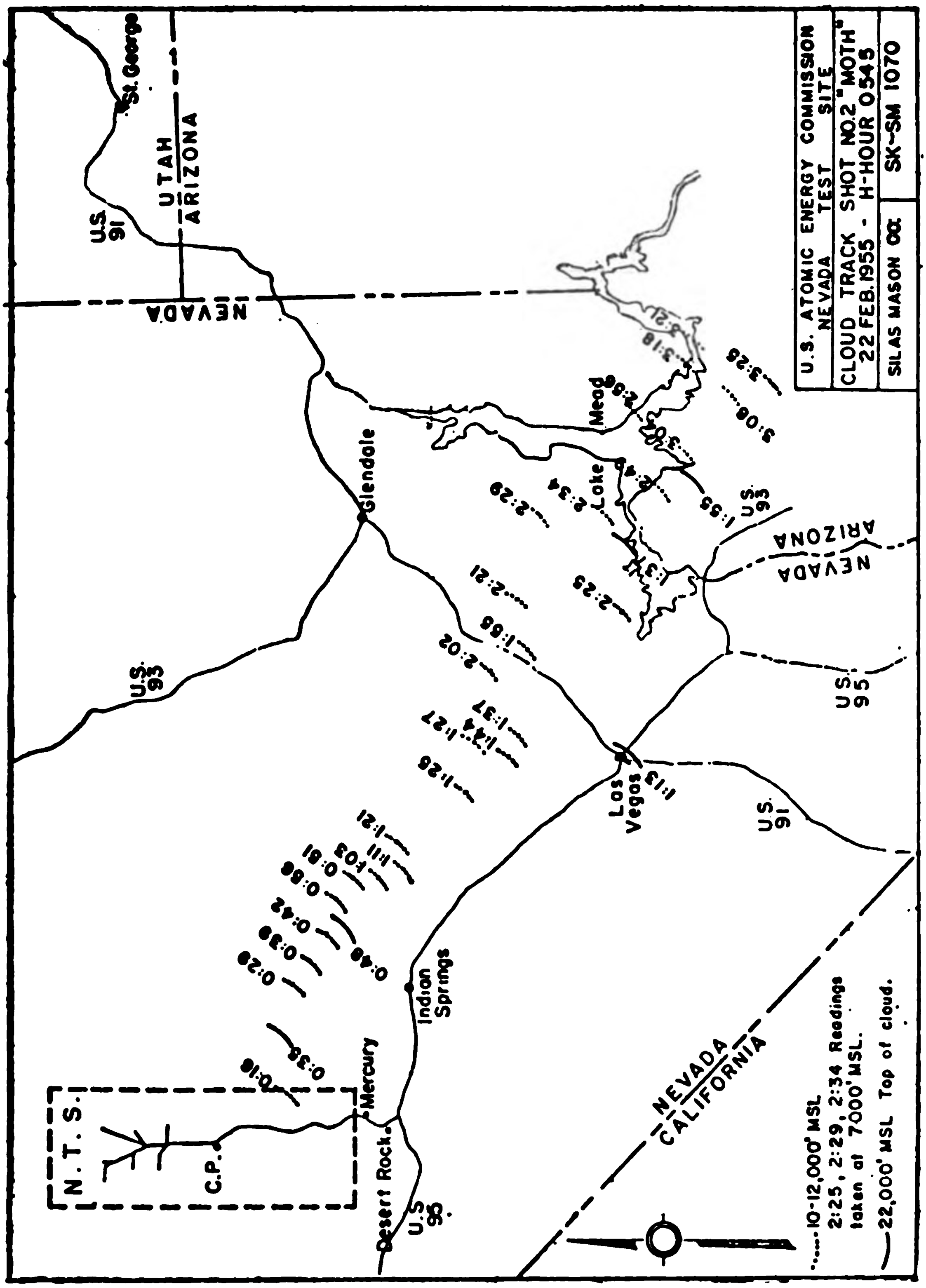
was not detected by the low-level terrain survey. The ground survey as well as the aerial survey showed that the 1 r. infinite contour crossed U. S. 93–91 at a nonpopulated place.

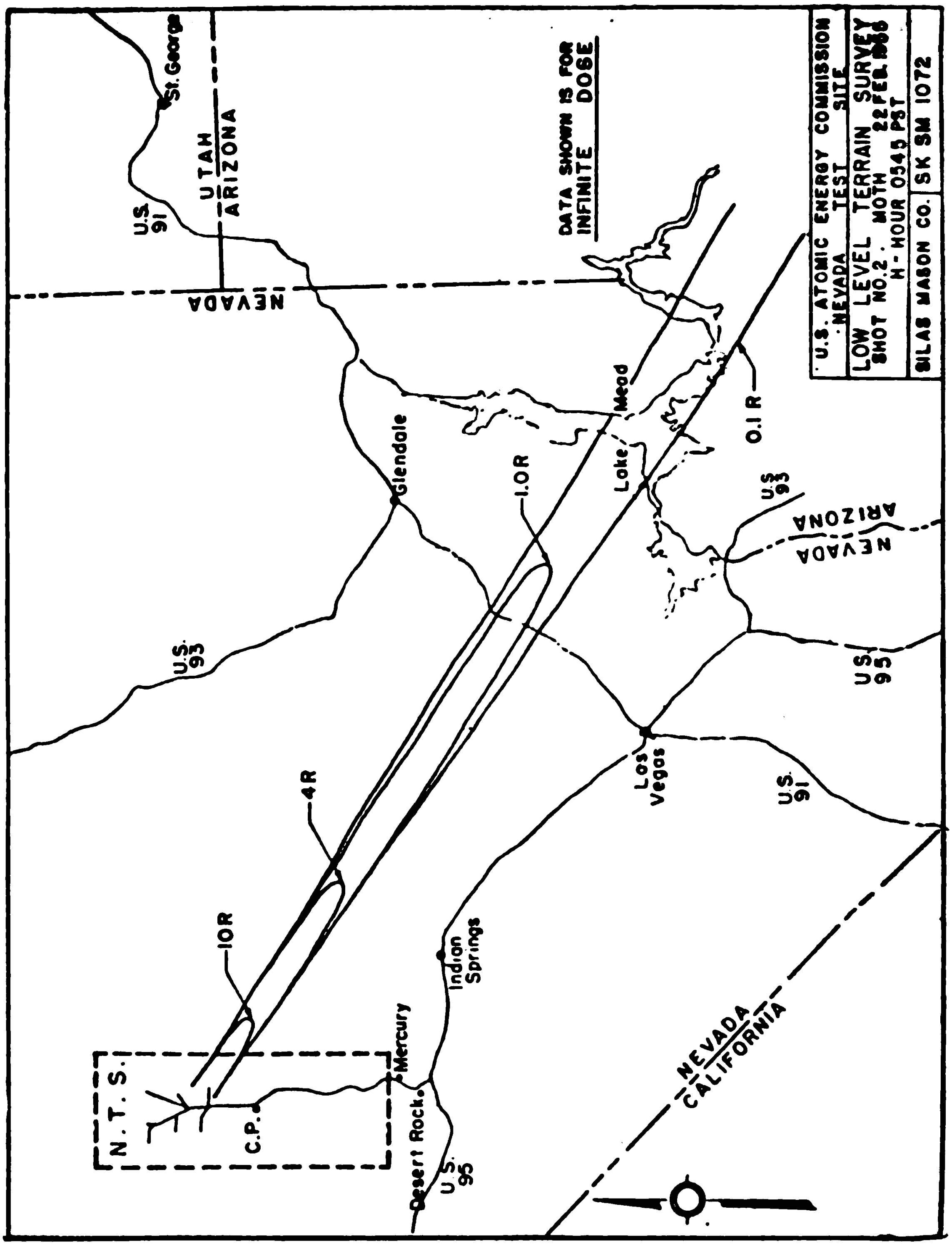
The maximum air radioactivity concentration measured was $4.4\times10^{-3}\mu c/m^3$. at Cedar City, Utah. This represents the average air concentration for a 28-hour period starting at shot time.

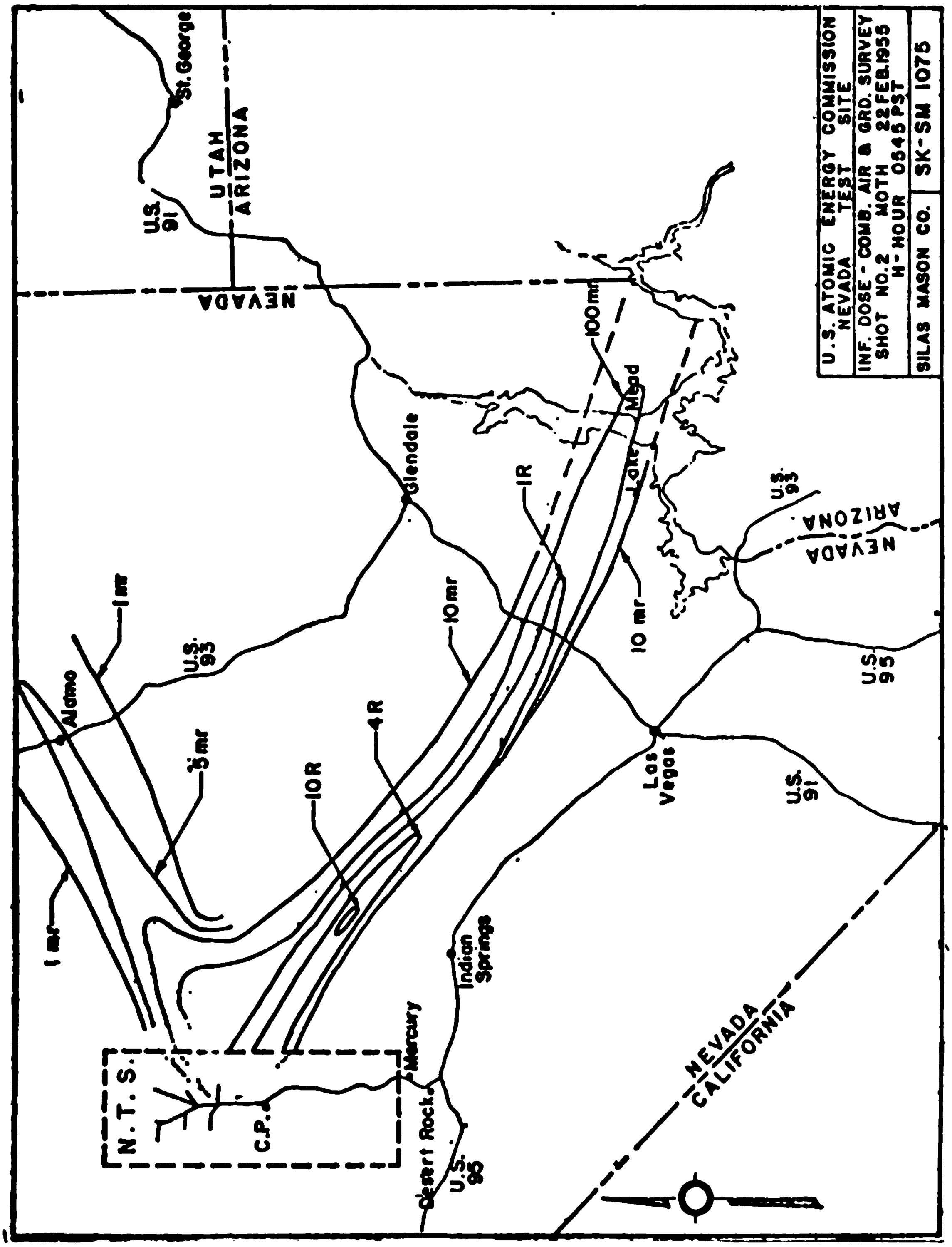
Moth: External gamma dose in populated areas and at selected nonpopulated points

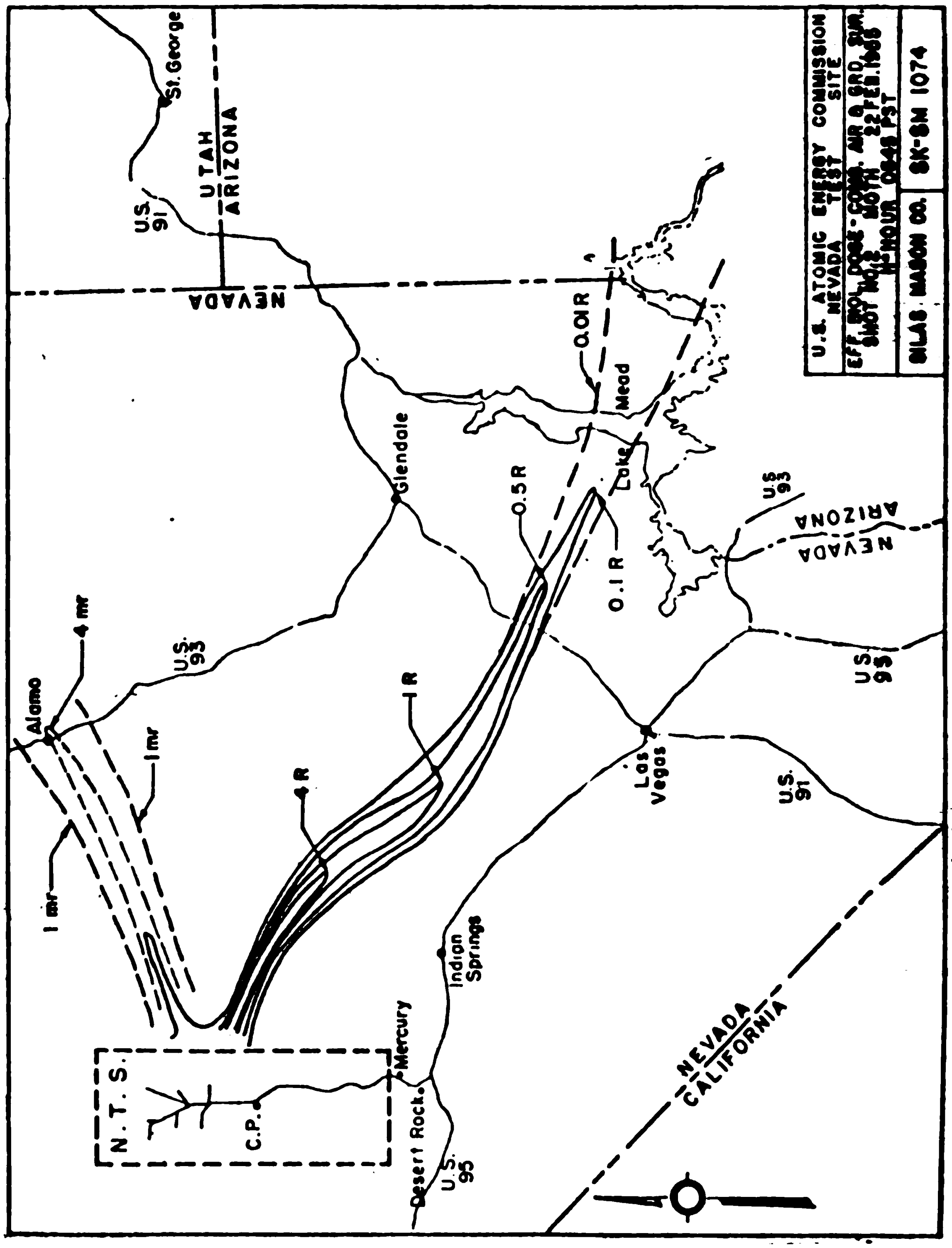
Location	Time of instrument reading (H+hours)	Gamma ground level (mr./hr.)	Time of fallout (H+hours)	Effective biological dose (mr.)	Infinite dose (mr.)
Populated areas:					
Dry Lake, Nev	6.3	6.0	2.2	130.0	235.0
Crystal, Nev	4.5	.5	2.5	7.0	13.0
Alamo, Nev	11.7	.1	1.5	4.4	7.7
Nonpopulated points:					
U. S. 91-93, 1 mile southwest of Dry Lake, Nev	6.4	29.0	2.2	650.0	1,200.0
22.8 miles north of Indian Springs, Nev	4.5	310.0	.8	5,900.0	10,000.0


U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
H-HOUR MINUS 4 FALLOUT PREDICTN
SHOT NO.2 MOTH 22 FEB.
H-HOUR 0545 PST
SILAS MASON CO.
SK-SM 1073
St. George
UTAH
ARIZONA
U.S. 91
NEVADA
Lake Mead
Glendale
U.S. 93
U.S. 93
ARIZONA
NEVADA
U.S. 95
0.1R
Las Vegas
U.S. 91
0.3R
0.2R
1.0R
4R
Indian Springs
Mercury
N. T. S.
C.P.
Desert Rock
U.S. 95
NEVADA
CALIFORNIA


U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
CLOUD TRACK SHOT NO.2 "MOTH"
22 FEB.1955 - H-HOUR 0545
SILAS MASON CO.
SK-SM 1070
St. George
UTAH
ARIZONA
NEVADA
U.S. 91
U.S. 93
U.S. 95
Glendale
Lake Mead
Las Vegas
Indian Springs
Mercury
Desert Rock
N. T. S.
C.P.
NEVADA
CALIFORNIA
10-12,000' MSL
2:25, 2:29, 2:34 Readings taken at 7000' MSL.
22,000' MSL Top of cloud.


U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
LOW LEVEL TERRAIN SURVEY
SHOT NO.2. MOTH
H-HOUR 0545 PST
SILAS MASON CO.
SK SM 1072
DATA SHOWN IS FOR INFINITE DOSE
St. George
U.S. 91
UTAH
ARIZONA
NEVADA
Glendale
U.S. 93
Lake Mead
1.0R
0.1 R
4R
10R
Los Vegas
U.S. 95
Indian Springs
Mercury
N. T. S.
C.P.
Desert Rock
NEVADA
CALIFORNIA


U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
INF. DOSE - COMB. AIR & GRD. SURVEY
SHOT NO.2 MOTH 22 FEB.1955
H-HOUR 0545 PST
SILAS MASON CO.
SK-SM 1075
St. George
U.S. 91
UTAH
ARIZONA
NEVADA
100mr
Lake Mead
Glendale
1R
U.S. 93
ARIZONA
NEVADA
10mr
10 mr
1mr
U.S. 93
U.S. 95
Alamo
3mr
4R
10R
Las Vegas
U.S. 91
1 mr
Indian Springs
Mercury
N. T. S.
C.P.
Desert Rock
U.S. 95
NEVADA
CALIFORNIA


U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
SILAS MASON CO.
SK-SM 1074
St. George
U.S. 91
UTAH
ARIZONA
NEVADA
0.01 R
Lake Mead
Glendale
0.5 R
0.1 R
U.S. 93
ARIZONA
NEVADA
4 mr
Alamo
1 mr
1 mr
1 R
4 R
Las Vegas
U.S. 95
U.S. 91
Indian Springs
Mercury
N. T. S.
C.P.
Desert Rock
U.S. 95
NEVADA
CALIFORNIA

Tesla

Tesla was a 300-foot tower detonation which was fired at 5:30 a. m., on March 1, 1955. The shot took place in test area 9 in Yucca Flat.

The airway closure pattern was as follows:

1. A circular area around Yucca Flat, with a radius of 60 nautical miles, was ordered closed at all altitudes from 5 a. m. to 8 a. m.
2. A sector bounded by radii at 65° and 125°, length of radius 60 nautical miles, was ordered closed at all altitudes from 5 a. m. to 10 a. m.
3. An extension of this sector to a radius of 90 nautical miles was ordered closed from 13,000 to 19,000 feet from 7:30 a. m. to 10 a. m.
4. A further extension of this sector to a radius of 160 nautical miles was ordered closed from 20,000 to 28,000 feet from 6:30 a. m. to 10 a. m.
5. At 7:47 a. m. the altitudes in sector (3) above were changed to close only between 16,000 to 19,000 feet and the circle in (1) above was opened at all altitudes except for the sector area (65°–125°).

The cloud was tracked as indicated on the accompanying map from H plus 35 minutes to H plus 2 hours and 55 minutes. In addition to reports from the B–25 tracker, reports from sampler aircraft were used to chart the cloud track. Maximum cloud height observed was 30,000 feet, which stabilized rather quickly to 27,000 feet. The cloud was tracked to a point near the northernmost part of Lake Mead, at which time aircraft were recalled.

The low level terrain survey was performed by one C–47 aircraft, which took off at H plus 7 hours and completed the mission at H plus 11 hours and 45 minutes.

The monitoring runs, which indicated activity substantially above background, were made on the Game Preserve Road north of U. S. 95; on U. S. 91 between Beaver Dam, Ariz., and Washington, Utah; along Utah 64 south of St. George, Utah; on Utah 15; on Utah 17; on Utah 18; along the Mormon Mesa Road north of U. S. 91; and on U. S. 93 approximately 27 miles south of Alamo, Nev.

The maximum effective biological dose for a populated area was 177 mr. at Santa Clara, Utah. The maximum effective biological dose at nonpopulated point was 34,000 mr. 10.5 miles south of Groom Road on Papoose Lake.

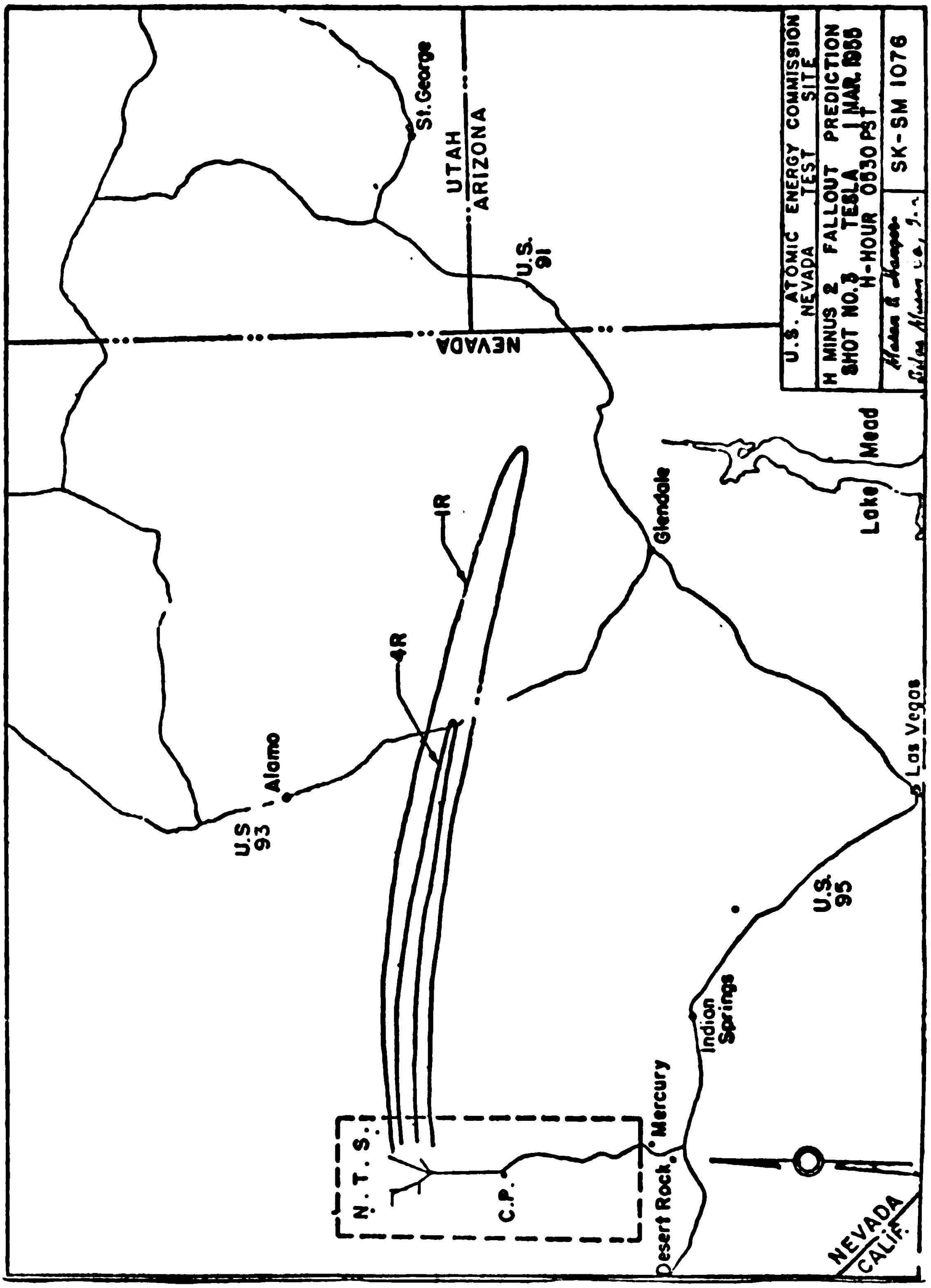
Approximately 190 individual monitoring readings above 0.1 mr/hr were recorded.

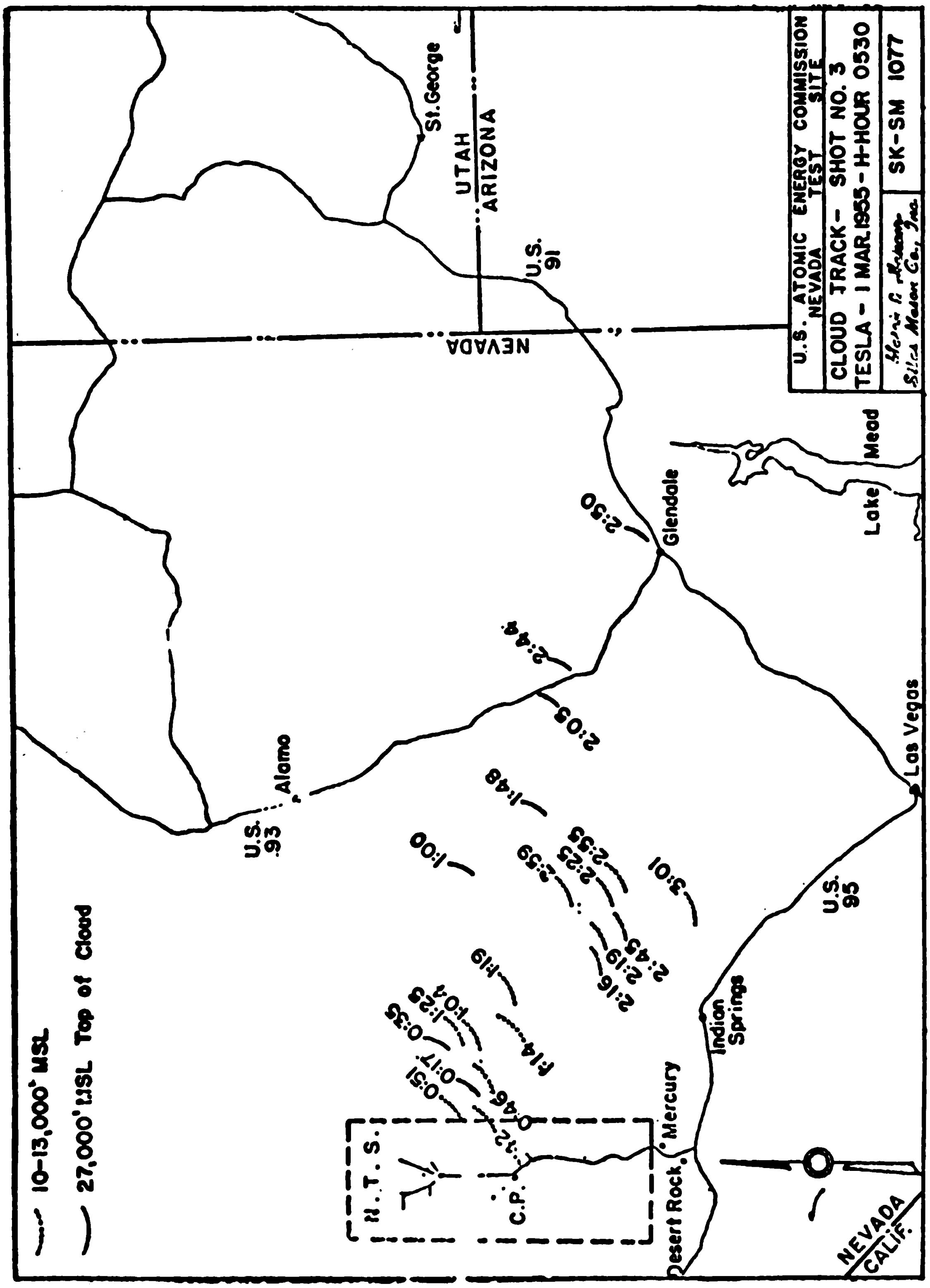
A comparison of the prediction map and the factual maps indiactes good agreement in both direction and magnitude of fallout. Ground monitoring did not indicate fallout in Carp, Nev., as shown on the terrain survey map. This fact was substantiated by the several film badges located in Carp for the entire series. The maximum series dose indicated by a film badge in Carp, Nev., was 60 mr. The 1 r. infinite-dose contour crossed U. S. 93 at a nonpopulated place.

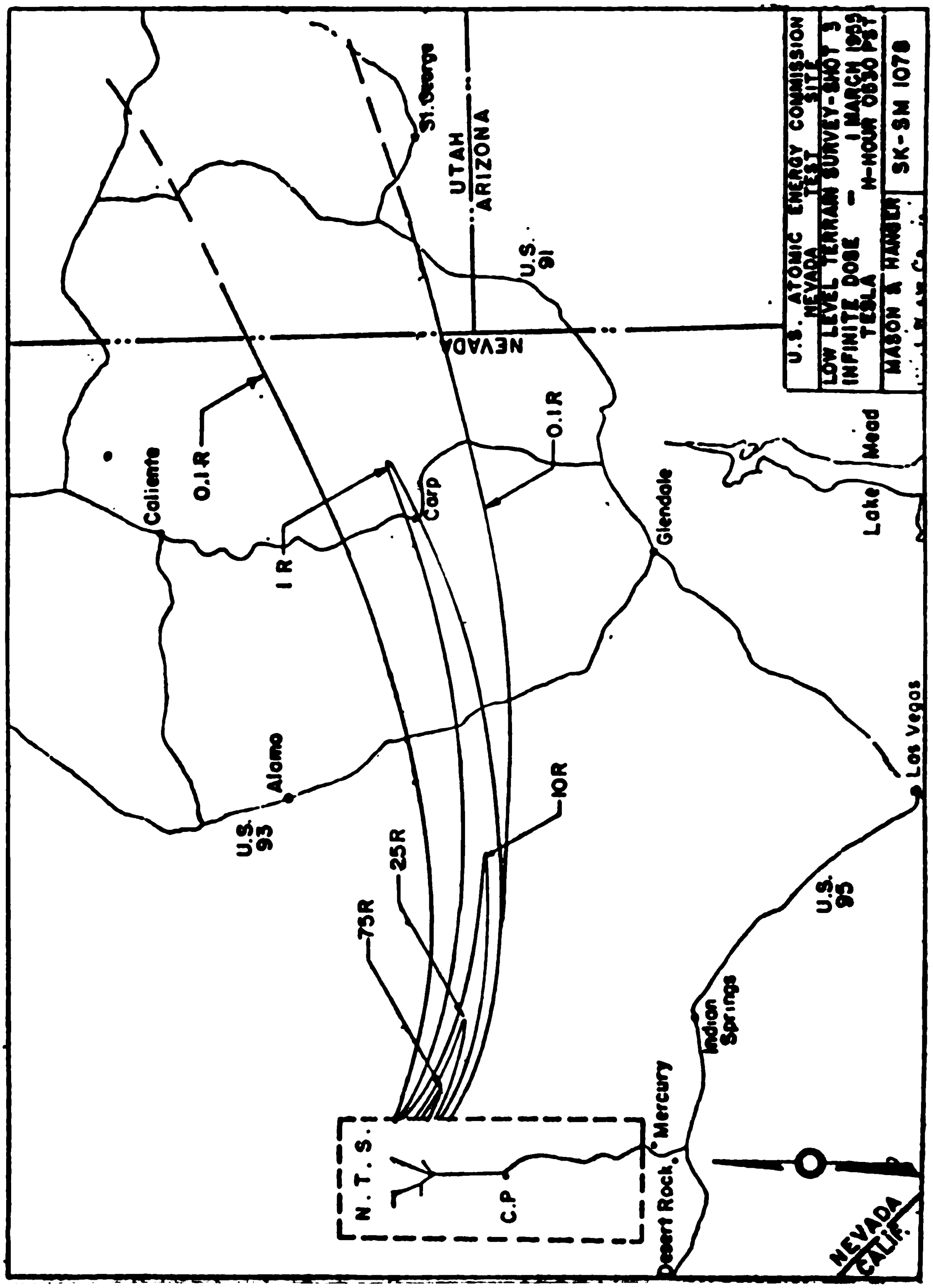
The maximum air concentration measured was $4.0\times10^{-2}\mu c/m^3$, at St. George, Utah. This represents the average air concentration for a 28-hour period starting at shot time.

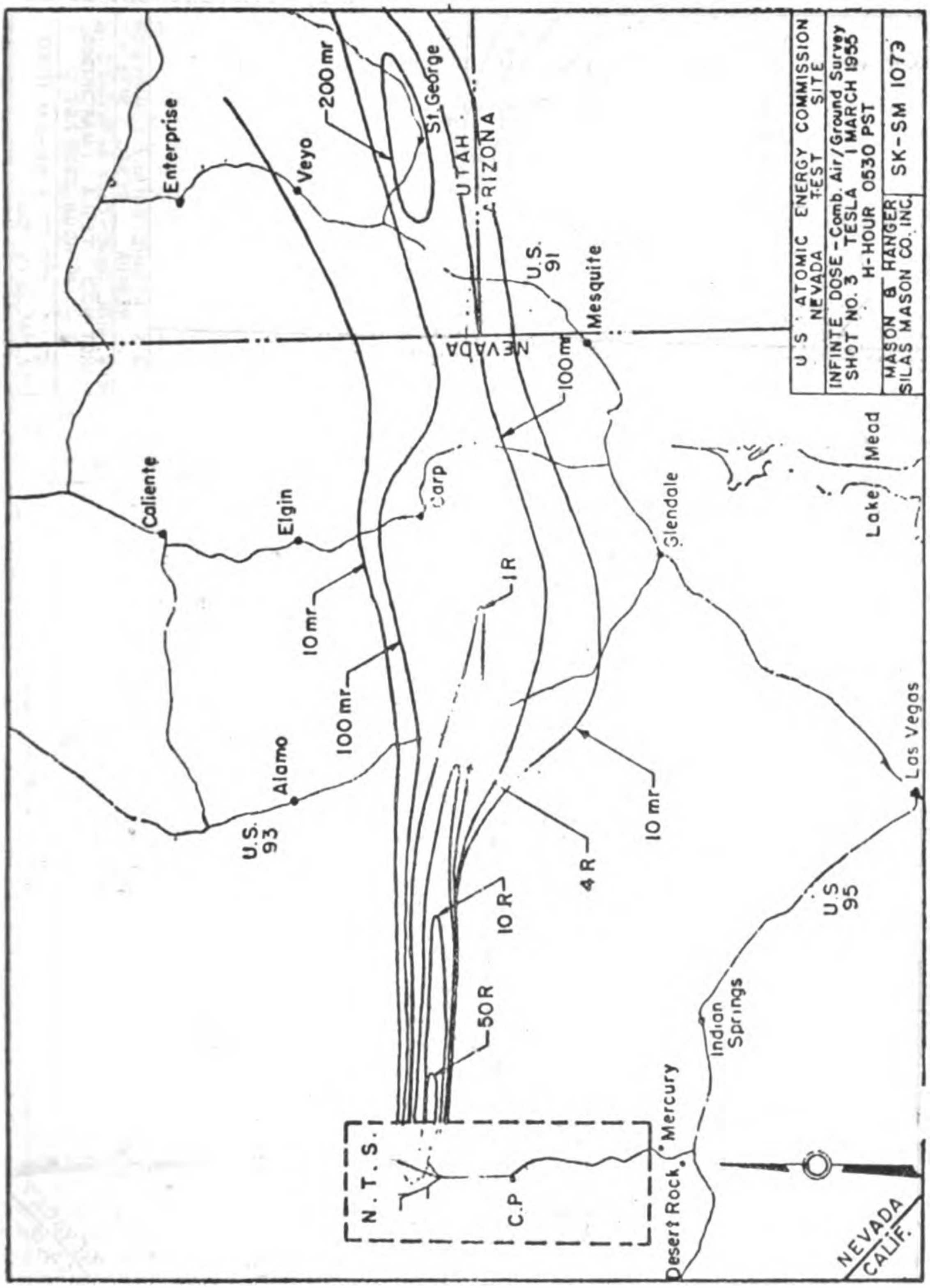
Tesla: External gamma dose in populated areas and at selected nonpopulated points

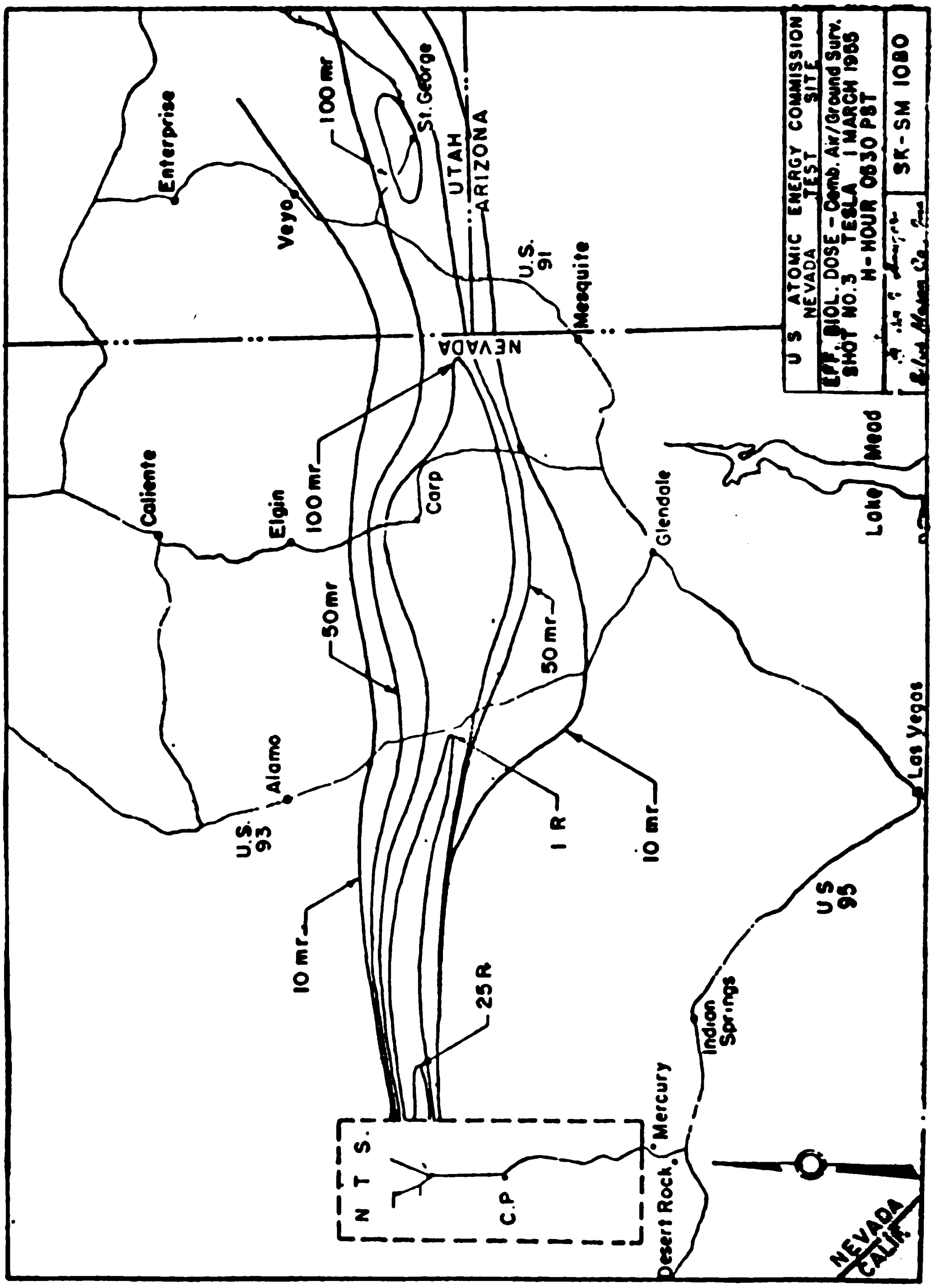
Location	Time of instrument reading (H+hours)	Gamma ground level (mr./hr.)	Time of fallout (H+hours)	Effective biological dose (mr.)	Infinite dose (mr.)
Populated areas:					
Santa Clara, Utah	11.3	6.0	9.0	177	350
St. George, Utah	10.2	4.0	9.2	103	210
Veyo, Utah	10.5	.5	9.0	14	27
Gunlock, Utah	10.9	.3	8.8	8	17
Washington, Utah	11.5	3.0	9.4	87	175
Hurricane, Utah	11.8	1.7	10.0	51	100
Toquerville, Utah	12.0	1.8	10.0	52	105
Anderson Junction, Utah	12.1	1.1	9.9	34	69
Leeds, Utah	12.2	1.4	9.8	44	88
Alamo, Nev	7.3	.3	4.0	7	12
Ash Springs, Nev	9.2	4.5	4.0	133	246
Nonpopulated points:					
U. S. 93, 27 miles south of Alamo, Nev	5.2	55.0	3.25–5.25	845	1,550
10.5 miles south of Groom Road on Papoose Lake	8.0	966.0	1.2	34,000	56,700


U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
H MINUS 2 FALLOUT PREDICTION
SHOT NO.3 TESLA 1 MAR. 1955
H-HOUR 0530 PST
SK-SM 1076
St. George
UTAH
ARIZONA
U.S. 91
NEVADA
Lake Mead
Glendale
1R
4R
Las Vegas
Alamo
U.S 93
U.S. 95
Indian Springs
Mercury
N. T. S.
C.P.
Desert Rock
NEVADA
CALIF.


U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
CLOUD TRACK - SHOT NO. 3
TESLA - 1 MAR. 1955 - H-HOUR 0530
SK-SM 1077
10-13,000' MSL
27,000' MSL Top of Cloud
St. George
UTAH
ARIZONA
NEVADA
U.S. 91
Glendale
Lake Mead
Las Vegas
Alamo
U.S. 93
U.S. 95
Indian Springs
Mercury
Desert Rock
N. T. S.
C.P.
NEVADA
CALIF.


U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
LOW LEVEL TERRAIN SURVEY-SHOT 3
INFINITE DOSE
TESLA
N-HOUR 0530 PST
MASON & HANGER
SK-SM 1078
St. George
UTAH
ARIZONA
U.S. 91
NEVADA
O.I.R
O.I.R
Caliente
Carp
I R
Glendale
Lake Mead
Alamo
U.S. 93
10R
25R
75R
Las Vegas
U.S. 95
Indian Springs
Mercury
Desert Rock
N. T. S.
C.P.
NEVADA
CALIF.


U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
INFINTE DOSE - Comb. Air/Ground Survey
SHOT NO. 3 TESLA 1 MARCH 1955
H-HOUR 0530 PST
MASON & HANGER
SILAS MASON CO. INC.
SK-SM 1073
Enterprise
Veyo
200 mr
St. George
UTAH
ARIZONA
U.S. 91
Mesquite
NEVADA
100 mr
Caliente
Elgin
Carp
Glendale
Lake Mead
10 mr
100 mr
1 R
Alamo
U.S. 93
Las Vegas
10 mr
4 R
10 R
U.S. 95
50 R
Indian Springs
Mercury
N. T. S.
C.P.
Desert Rock
NEVADA
CALIF.


U S ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
EFF. BIOL. DOSE - Comb. Air/Ground Surv.
Enterprise
Veyo
St. George
100 mr
UTAH
ARIZONA
U.S. 91
Mesquite
NEVADA
Caliente
Elgin
100 mr
Carp
Glendale
Lake Mead
50 mr
50 mr
Alamo
U.S. 93
1 R
10 mr
Las Vegas
10 mr
US 95
25 R
Indian Springs
Mercury
Desert Rock
N T S.
C.P.
NEVADA
CALIF.

Turk

Turk was a 500-foot tower detonation which was fired at 5:20 a. m. on March 7, 1955. The detonation took place in test area 2 in Yucca Flat.

The airway-closure pattern was as follows:

1. A circular area around Yucca Flat, with a radius of 60 nautical miles, was closed at all altitudes from 5 a. m. to 9:30 a. m.
2. An area southwest of the test site, bounded as described below, was ordered closed from 25,000 to 30,000 feet from 7 a. m. to 12:30 p. m. From EH0000 due south to EG0000, then southwest to the east edge of airway Amber 1 at Bakersfield, then along the east edge of Amber 1 to AH0000, then due east to EH0000.
3. An area north and east of the test site, bounded as described below, was ordered closed from 32,000 feet up from 6:30 a. m. to 12:30 p. m. From EH 0000 on a bearing of 42° true for 320 nautical miles, then due south to JG4500, then due west to EG0000, then due north to EH0000.

At 10:23 a. m. conditions were such that closure time in areas 2 and 3 was cut back to 11 a. m. instead of 12:30 p. m.

The cloud was tracked as shown on the accompanying map from H plus 30 minutes to H plus 4 hours and 55 minutes. Tracking was performed by the following aircraft:

B–50: initially at 28,000 feet and subsequently at 31,000 and 25,000 feet.
B–29: 20,000 to 23,000 feet.
B–25: 11,000 to 14,000 feet.
Samplers (F–84): 36,000 to 42,000 feet.

Maximum cloud height observed was 42,500 feet. The wind pattern at shot time was such that the cloud became broken and dispersed in a very short time, with two general zones containing most of the cloud components. At altitudes up to about 28,000 feet, the cloud generally drifted into the northwest quadrant from GZ, with the maximum distance being approximately 85 nautical miles at 20,000 to 23,000 feet bearing from CP 315° true. The second zone was between 40° and 105° true at high altitudes (above 30,000 feet), extending to 105 nautical miles at 105° true and about 130 nautical miles at about 75° true. In many instances, the cloud appeared to have several different leading edges, and at times doubled back on its previous path.

A low-level terrain survey was flown on D-day by one C–47 from about H plus 6.5 to H plus 11. The fallout pattern indicated by this flight was quite scattered, and on D plus 1, additional flights were made by the C–47 and by a helicopter.

The pattern shown on the accompanying map was drawn using data from all three flights. It is evident that, just as the cloud-track pattern was widespread and, in several directions, so also was the fallout pattern.

Monitoring runs, which indicated activity substantially above background, were made along U. S. 93 in the vicinity of Pioche, Nev.; on Utah 21 between Beaver, Utah, and the Utah-Nevada State line; on U. S. 95 between Beatty, Nev., and Goldfield, Nev.; along Utah 15 in the Toquerville, Utah, area; along U. S. 6 between Tonopah, Nev., and Ely, Nev.; in the vicinity of Ely, Nev.; along Nevada 25 between Crystal Springs, Nev., and Warm Springs, Nev.; and on the desert roads northeast and west of the Nevada test site.

The maximum effective biological dose for a populated area was 157 mr. at Warm Springs, Nev. The maximum effective biological dose at a nonpopulated point was 30,500 mr. 15 miles west of Nevada test site on a desert road.

Approximately 220 individual monitoring readings above 0.1 mr./hr. were recorded.

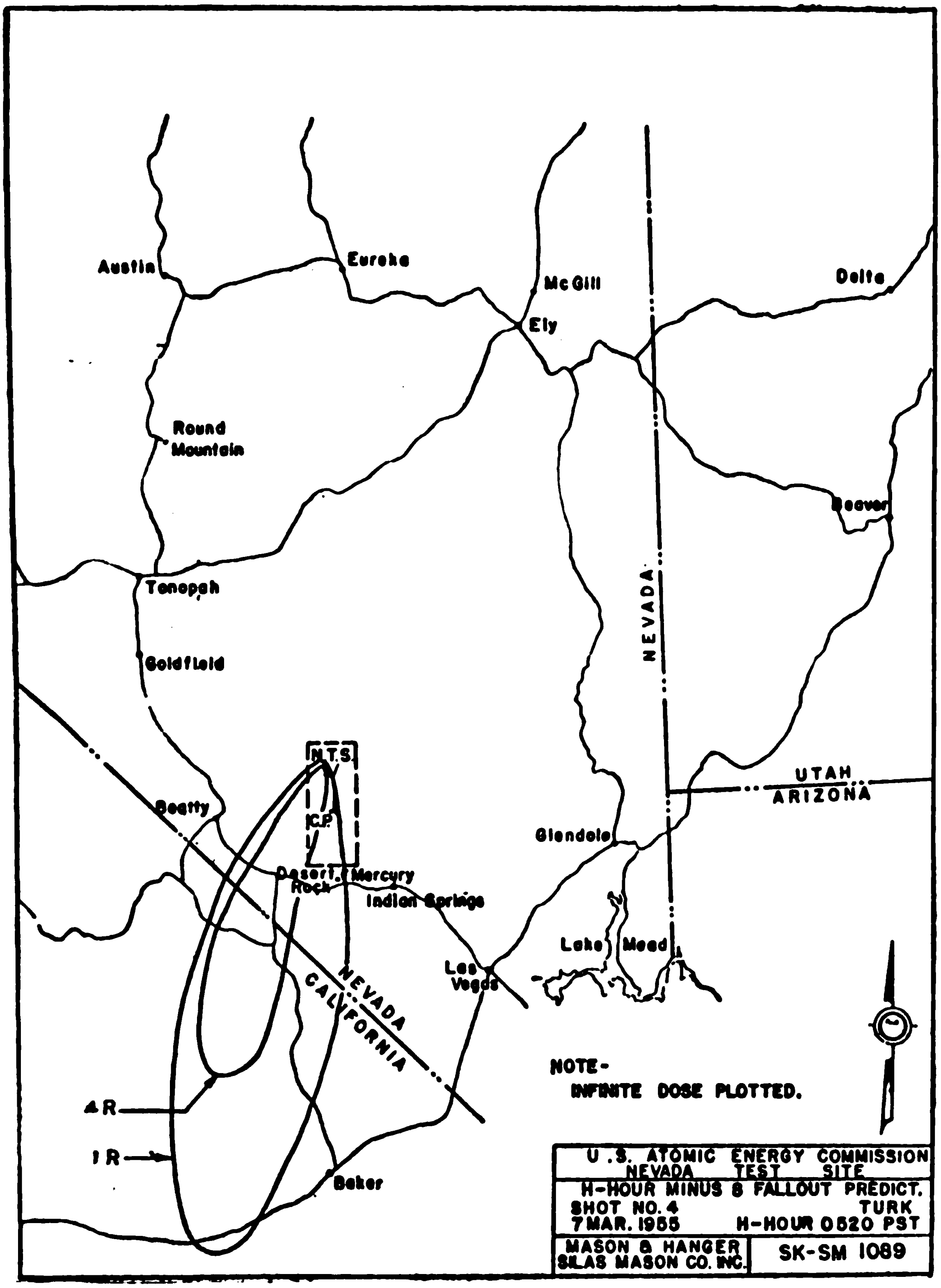
A comparison of the prediction map and the factual maps indicates an extreme overprediction. This came about as a result of a frontal system change which occurred near shot time. This frontal change resulted in a drastic reduction in wind speeds and a rapid shifting of wind directions.

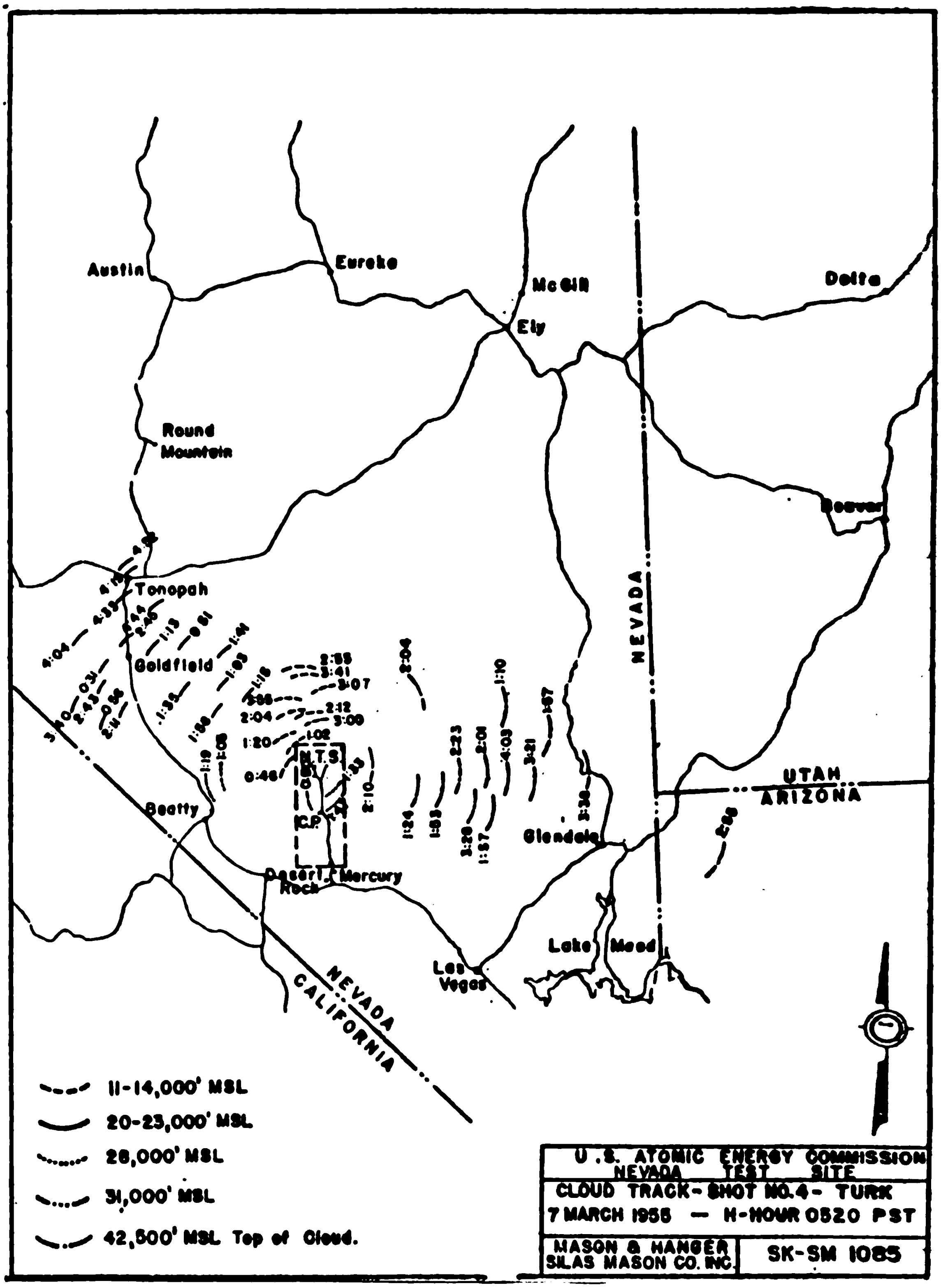
The ground-survey map shows the wide scattering of fallout under the meteorological conditions mentioned above. Also, the effects of terrain on the fallout pattern are quite pronounced. It is apparent from this map that the 1 r. isodose contour did not intersect any major highways.

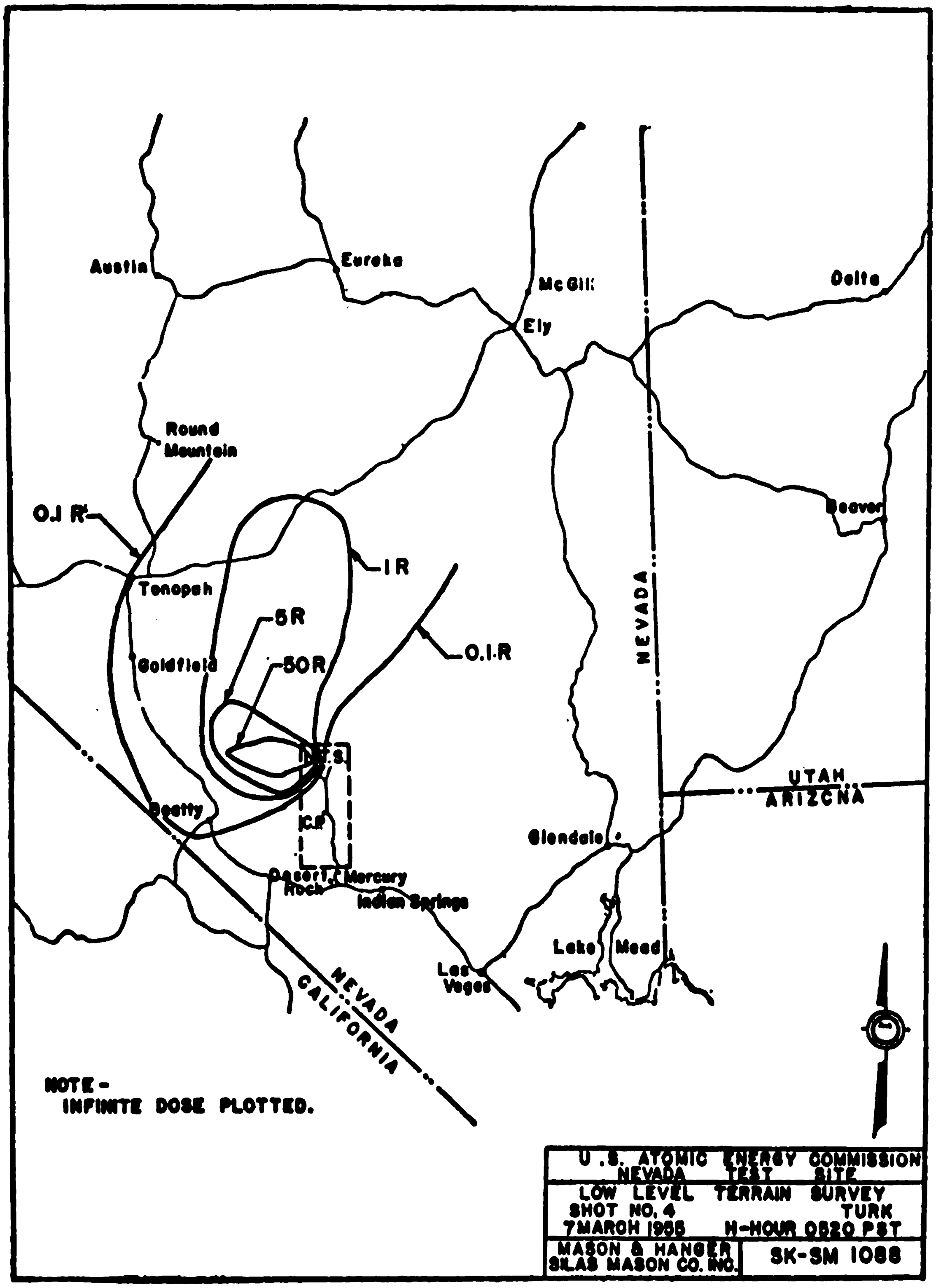
The maximum air radioactivity concentration measured was $1.7\times10^{-3}\mu c/m^3$. at Currant, Nev. This represents the average air concentration for a 29-hour period starting three-quarters of an hour after shot time.

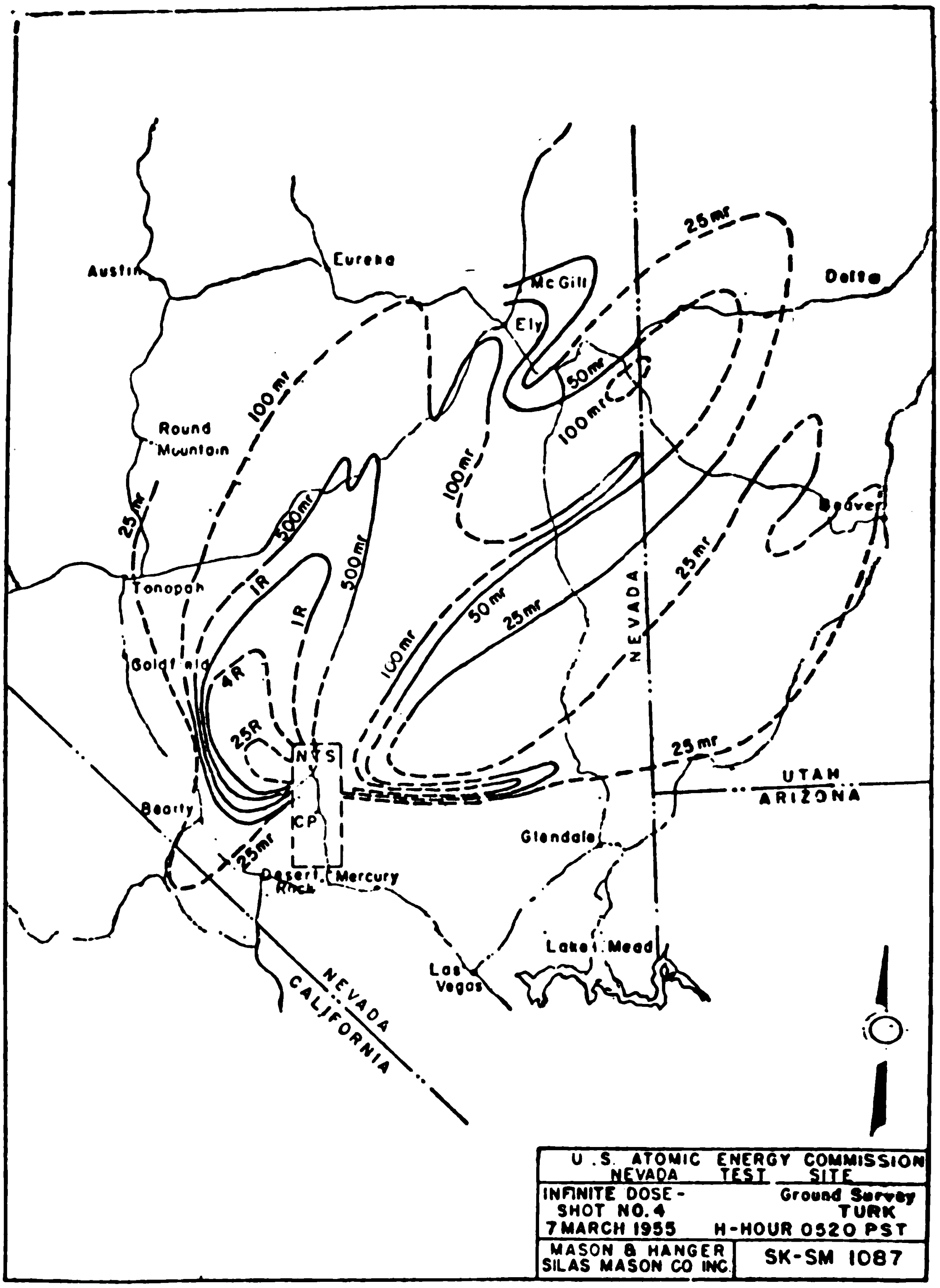
Turk: External gamma dose in populated areas and at selected nonpopulated points

Location	Time of instrument reading (H+hours)	Gamma ground level (mr./hr.)	Time of fallout (H+hours)	Effective biological dose (mr.)	Infinite dose (mr.)
Populated areas:					
Rockville, Utah	11.3	0.10	11.0	3	6
Toquerville, Utah	12.2	.37	11.0	11	24
Lincoln Mine, Nev	16.7	.70	8.0	34	65
Frisco, Utah	19.8	.20	15.0	17	35
Desert Game Experiment Station, Utah	30.7	.23	14.5	19	41
Garrison, Utah	32.0	.38	15.0	34	71
Baker, Utah	32.1	.58	15.0	53	113
Pioche, Nev	13.9	.30	11.7	11	21
Ursine, Nev	14.2	.25	13.0	9	18
McGill, Nev	33.8	.17	18.0	16	32
Ely, Nev	28.4	1.00	17.5	74	156
New Ruth, Nev	34.4	.37	17.5	34	74
Preston, Nev	30.0	1.00	15.5	80	172
Lund, Nev	28.5	1.18	15.1	93	192
Currant, Nev	29.4	.98	14.6	79	164
Lockes Ranch, Nev	31.6	1.48	13.5	132	279
Wahwa Springs, Utah	30.1	.10	15.0	8	17
Warm Springs, Nev	34.8	1.50	12.0	157	324
Nonpopulated points:					
6 miles south of Lockes on U. S. 6	31.0	3.00	13.4	253	549
15 miles west of Nevada test site on desert road	31.2	200.00	2.0	30,500	54,000


Austin
Eureka
McGill
Ely
Delta
Round Mountain
Beaver
Tonopah
Goldfield
NEVADA
N.T.S.
C.P.
Beatty
UTAH
ARIZONA
Glendale
Desert Rock
Mercury
Indian Springs
Lake Mead
Las Vegas
NEVADA
CALIFORNIA
4 R
1 R
Baker
NOTE-
INFINITE DOSE PLOTTED.
U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
H-HOUR MINUS 8 FALLOUT PREDICT.
SHOT NO. 4 TURK
7 MAR. 1955 H-HOUR 0520 PST
MASON & HANGER
SILAS MASON CO. INC.
SK-SM 1089


Austin
Eureka
McGill
Ely
Delta
Round Mountain
Beaver
Tonopah
Goldfield
NEVADA
UTAH
ARIZONA
N.T.S.
C.P.
Beatty
Desert Rock
Mercury
Glendale
Lake Mead
Las Vegas
NEVADA
CALIFORNIA
11-14,000' MSL
20-23,000' MSL
26,000' MSL
31,000' MSL
42,500' MSL Top of Cloud.
U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
CLOUD TRACK-SHOT NO.4- TURK
7 MARCH 1955 — H-HOUR 0520 PST
MASON & HANGER
SILAS MASON CO. INC.
SK-SM 1085


Austin
Eureka
McGill
Delta
Ely
Round Mountain
O.I R
Tonopah
I R
5 R
50 R
O.I.R
Goldfield
N.T.S.
C.P.
Beatty
Desert Rock
Mercury
Indian Springs
Las Vegas
Glendale
Lake Mead
Beaver
NEVADA
UTAH
ARIZONA
NEVADA
CALIFORNIA
NOTE -
INFINITE DOSE PLOTTED.
U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
LOW LEVEL TERRAIN SURVEY
SHOT NO. 4 TURK
7 MARCH 1955 H-HOUR 0520 PST
MASON & HANGER
SILAS MASON CO. INC.
SK-SM 1088



Hornet

Hornet was a 300-foot tower detonation which was fired at 5:20 a. m. on March 12, 1955. The shot took place in test area 3 in Yucca Flat.

The airway closure pattern was as follows:

1. A circular area around Yucca Flat, with a radius of 60 nautical miles, was closed at all altitudes from 5 a. m. to 9 a. m.
2. A sector, bounded by radii at 70° and 130°, length of radius 125 nautical miles, was ordered closed from 21,000 to 32,000 feet from 6:50 a. m. to 12 noon.

3. That part of the above sector extending between radial distances of 125 nautical miles and 200 nautical miles was ordered closed from 30,000 feet to 40,000 feet from 6 a. m. to 11: 30 a. m.

4. At 9: 15 a. m., the situation was such that sectors 2 and 3, above, were opened after 10: 30 a. m.

The cloud was tracked at three levels: 10,000 to 14,000; 23,000 to 30,000; and 36,000 feet, by B-35, B-29, and sampler aircraft respectively. The track obtained is shown on the accompanying map. Maximum cloud height observed was 39,300 feet. The cloud was tracked to a distance of about 140 nautical miles from the CP, becoming so dispersed at this distance as to render further tracking impractical.

A low-level terrain survey mission was flown by one C-47 aircraft from H plus 6 hours and 40 minutes to H plus 11 hours. The fallout pattern obtained from the data reported is shown on the accompanying map. The fallout pattern was determined out to a distance of 100 nautical miles at which point low radiation levels made continuation impracticable.

Monitoring runs, which indicated activity substantially above background, were made on the game preserve road north of U. S. 95; on the Mormon Mesa road north of U. S. 91; on U. S. 91 between the Nevada-Utah State line and Glendale, Nev.; along U. S. 93 between Panaca, Nev., and Glendale, Nev.: on Nevada 12; on Nevada 40; along the desert road north of Indian Springs, Nev.; along the roads in the Moapa Indian Reservation; and on the desert roads just east of the Nevada test site.

The maximum effective biological dose for a populated area was 293 mr. at Glendale, Nev. The maximum effective biological dose at a nonpopulated point was 3,502 mr. 29.5 miles north of Indian Springs, Nev.

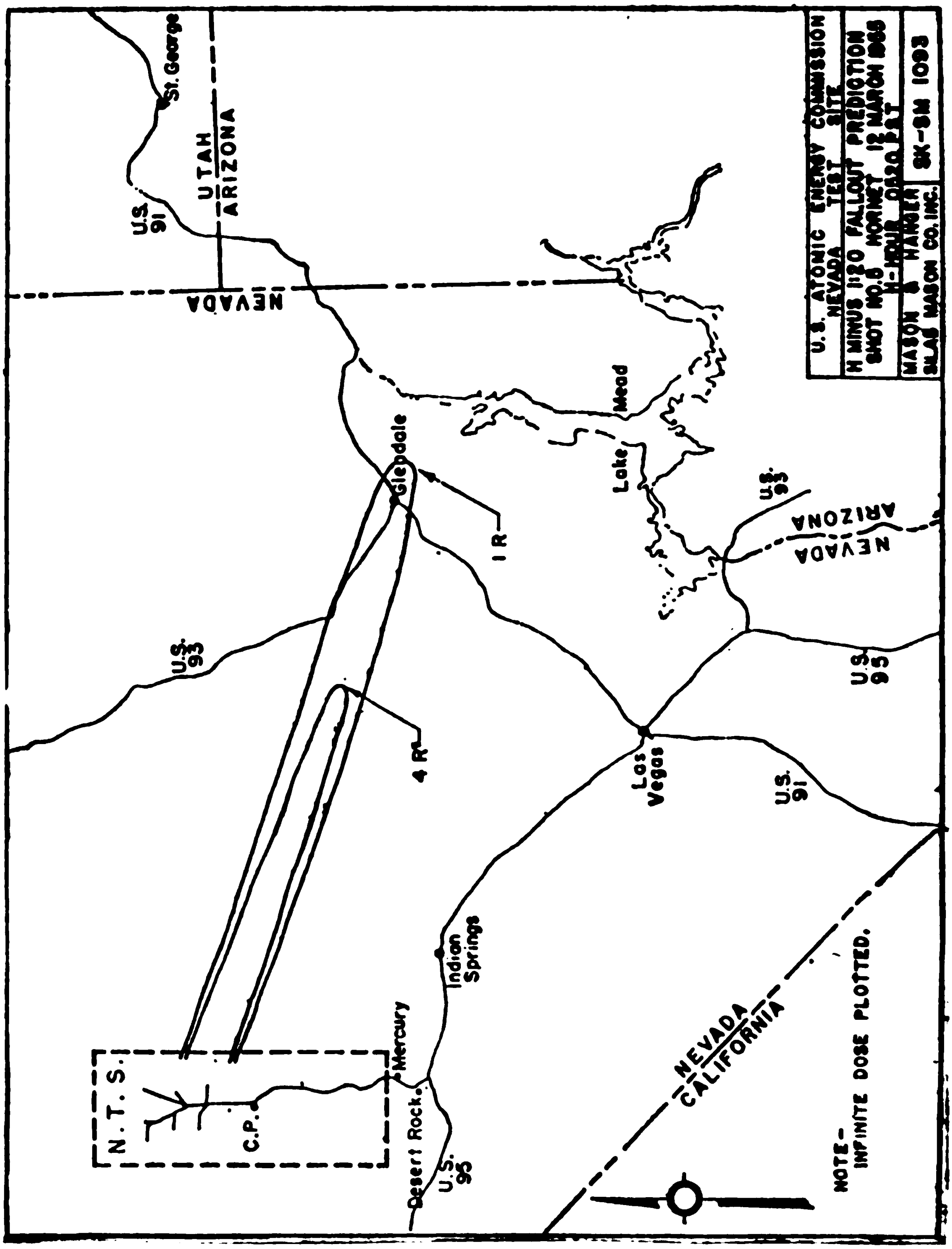
Approximately 300 individual monitoring readings above 0.1 mr/hr were recorded.

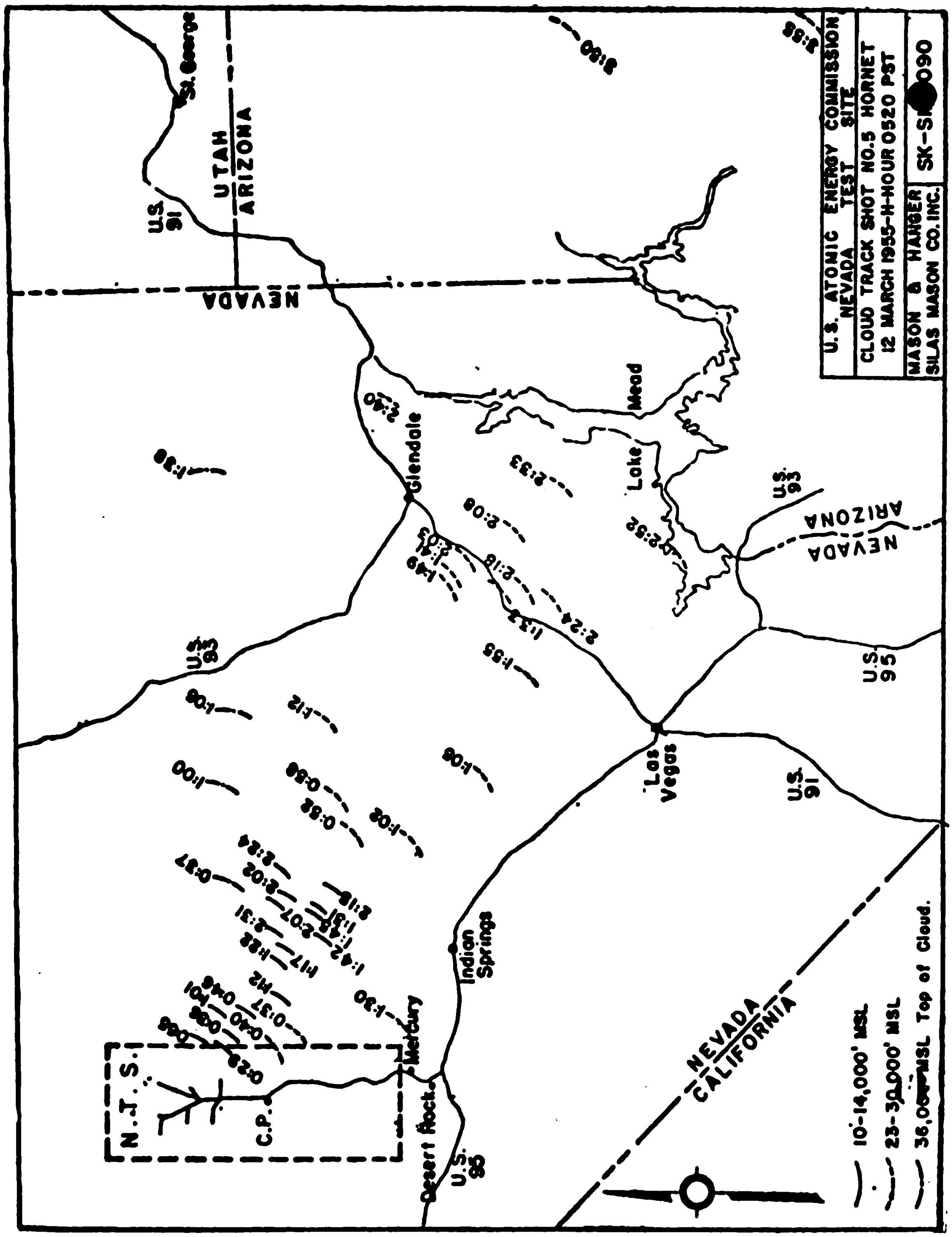
A comparison of the prediction map and the factual maps indicates good agreement in direction and relatively good agreement in magnitude. However, the 4 r. and 1 r. contours actually extended about 50 percent of the predicted distance. The ground survey map shows the results of directional shear which resulted in fallout in the Alamo, Nev., area. It also indicated the uneven isodose contours that may be expected, particularly at relatively low doses. It is apparent from the ground survey maps that the 1 r. isodose contour did not intersect any major highways.

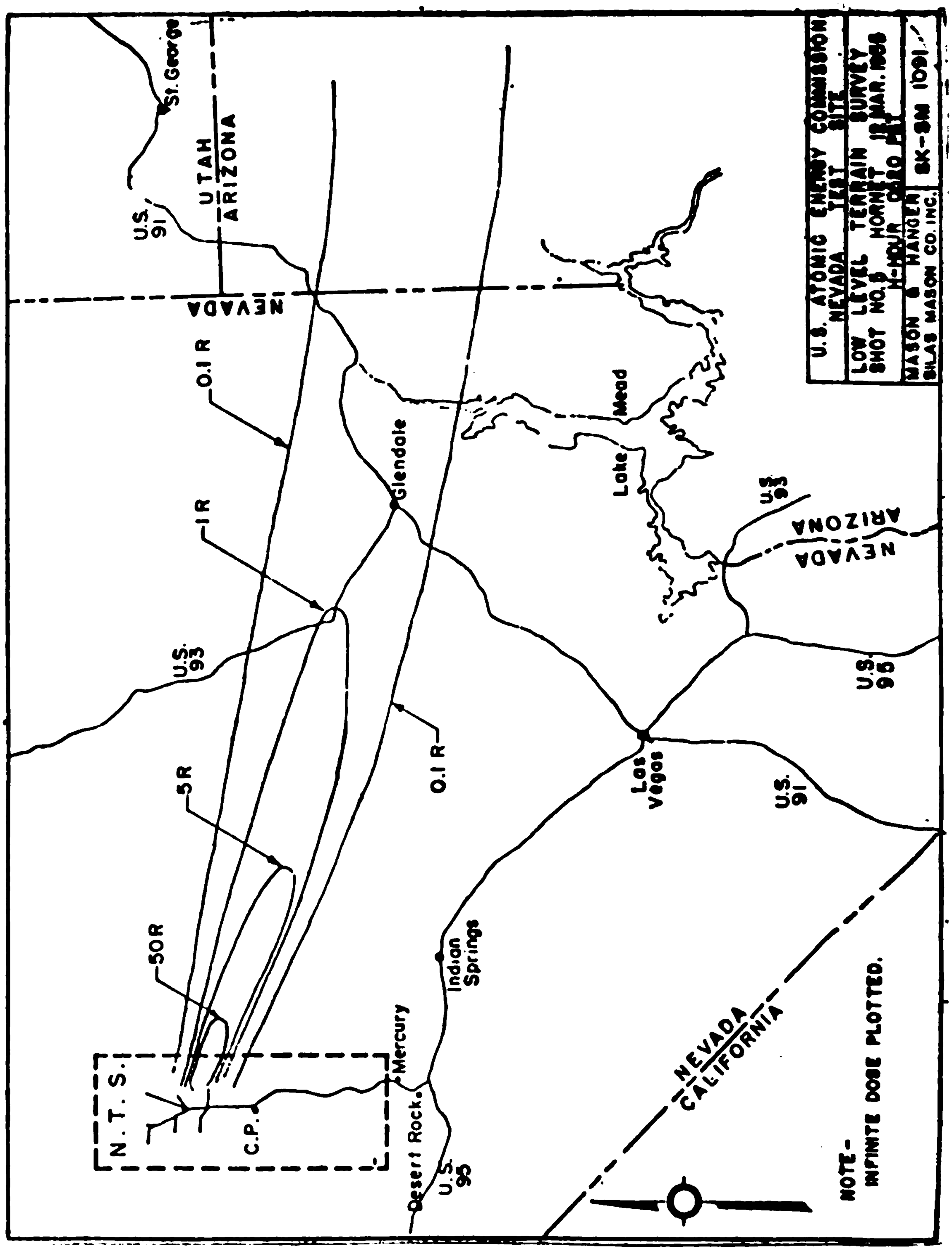
The maximum air radioactivity concentration measured was 1.2 by 10^{-3} $\mu c/m^3$ at Glendale, Nev. This represents the average air concentration for a 28-hour period starting at shot time.

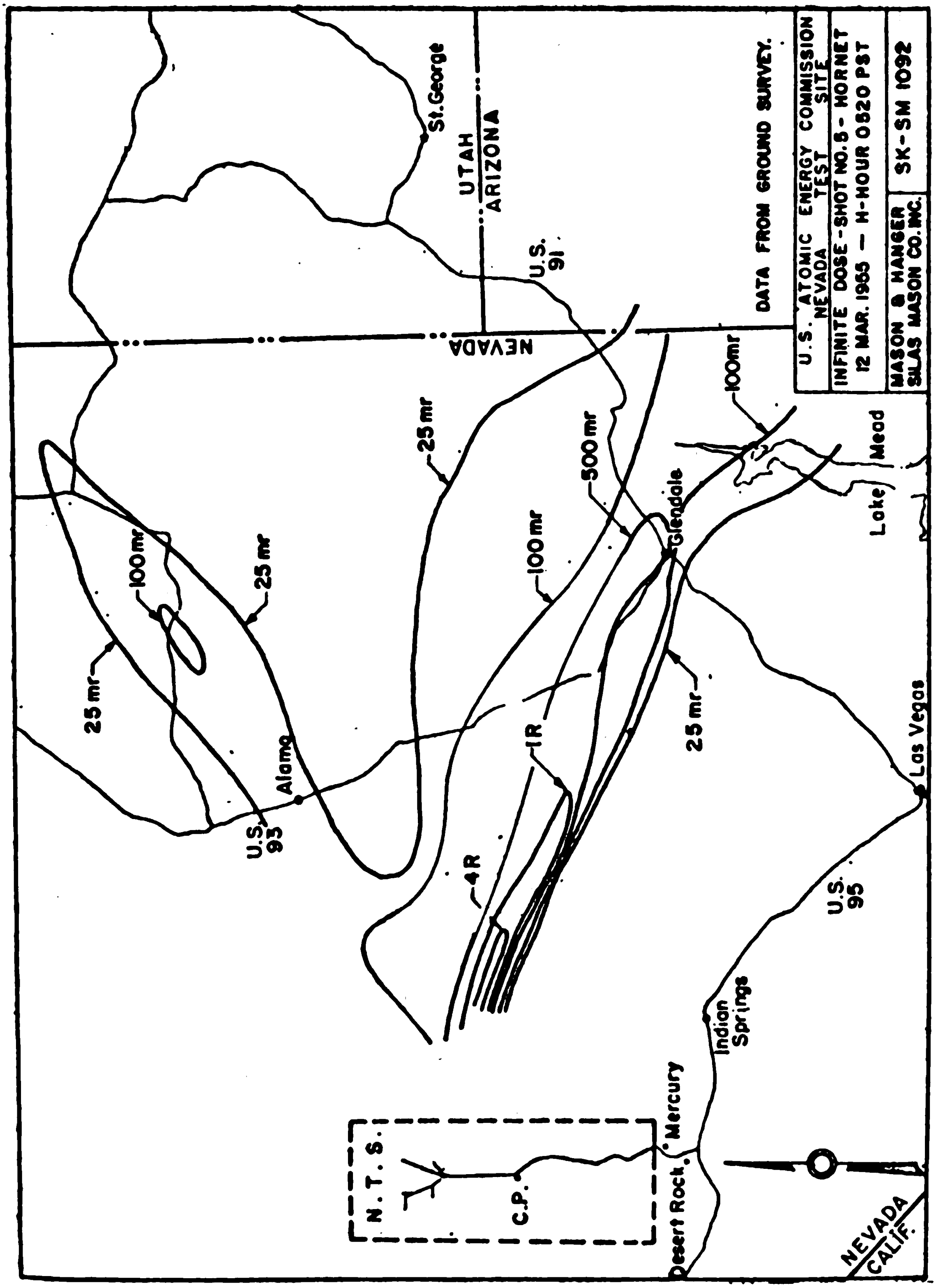
Hornet: External gamma does in populated areas and at selected nonpopulated points

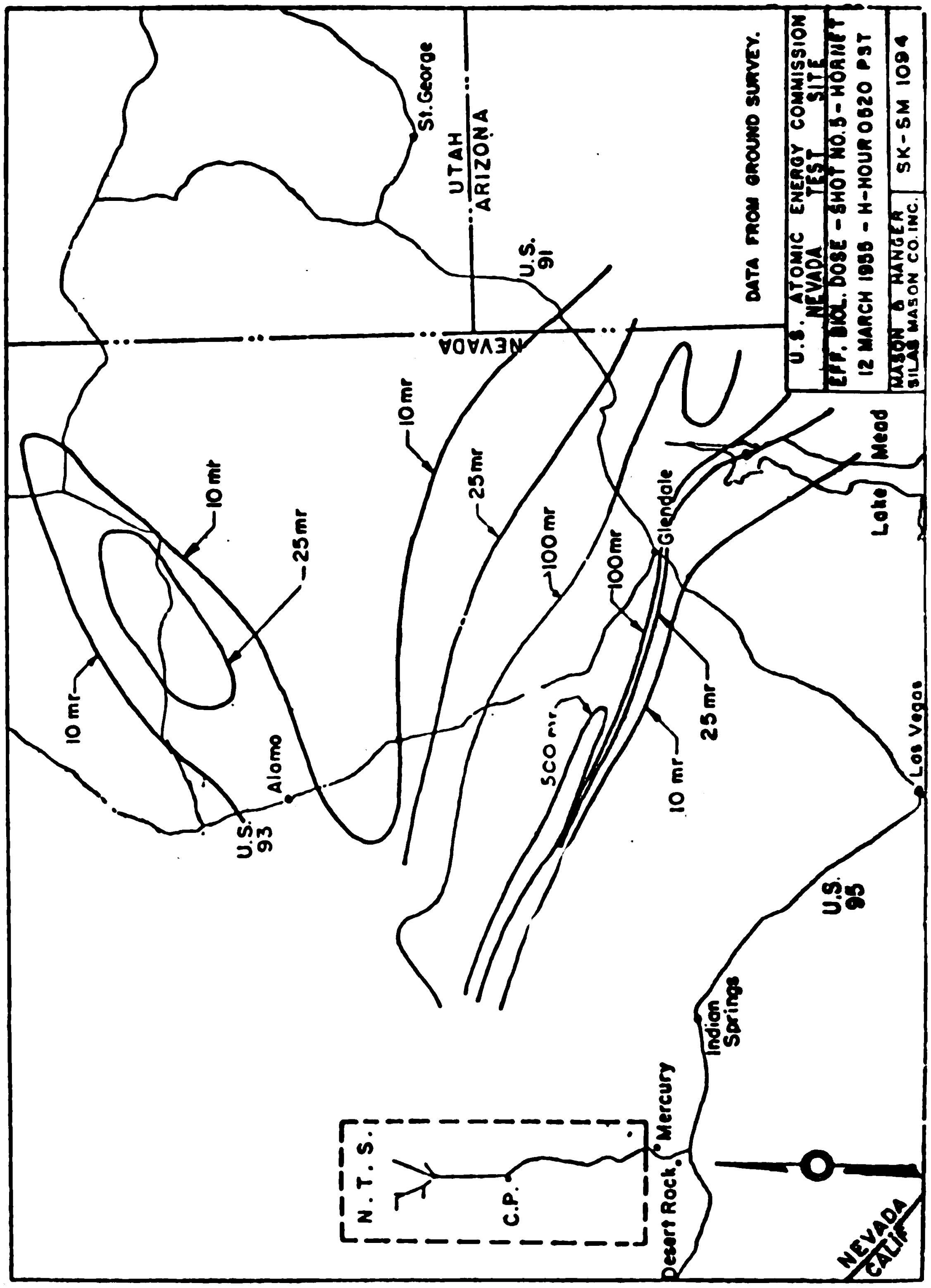
Location	Time of instrument reading (H+hours)	Gamma ground level (mr./hr.)	Time of fallout (H+hours)	Effective biological dose (mr.)	Infinite dose (mr.)
Populated areas:					
Riverside, Nev	8.3	2.0	8.0	43	84
Bunkerville, Nev	11.7	.6	8.6	19	37
Mesquite, Nev	12.0	.3	8.7	10	19
Littlefield, Ariz	12.5	.3	9.3	10	20
Glendale, Nev	7.7	14.0	6.0	293	564
Logandale, Nev	9.1	.7	7.3	17	33
Carp, Nev	10.4	.4	8.5	10	20
Moapa Indian Reservation, Nev	6.5	10.0	5.5	176	336
Warm Springs Ranch, Nev	5.2	7.0	5.0	97	184
Caliente, Nev	8.5	2.8	8.5	60	119
Panaca, Nev	9.5	.7	9.9	17	33
Alamo, Nev	6.9	.14	5.3	3	5
Ash Springs, Nev	7.3	.5	5.3	9	18
Nonpopulated points:					
U. S. 91, 5 miles east of Glendale, Nev	11.9	10.0	7.1	342	664
29.5 miles north of Indian Spring, Nev	4.8	210.0	1.8	3,502	6,124


U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
NOTE-
INFINITE DOSE PLOTTED.
St. George
UTAH
ARIZONA
NEVADA
CALIFORNIA
Lake Mead
Glendale
Las Vegas
Indian Springs
Mercury
Desert Rock
N. T. S.
C.P.
1 R
4 R
U.S. 91
U.S. 93
U.S. 95


U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
CLOUD TRACK SHOT NO.5 HORNET
12 MARCH 1955-H-HOUR 0520 PST
MASON & HANGER
SILAS MASON CO. INC.
10-14,000' MSL
23-30,000' MSL
36,000' MSL Top of Cloud.
St. George
UTAH
ARIZONA
NEVADA
U.S. 91
U.S. 93
U.S. 95
Glendale
Lake Mead
Las Vegas
Indian Springs
Mercury
Desert Rock
N.T.S.
C.P.
NEVADA
CALIFORNIA


U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
LOW LEVEL TERRAIN SURVEY
MASON & HANGER
SILAS MASON CO. INC.
SK-SM 1091
St. George
UTAH
ARIZONA
NEVADA
U.S. 91
O.I R
Glendale
Lake Mead
U.S. 93
I R
U.S. 95
Las Vegas
5 R
50 R
Indian Springs
Mercury
N. T. S.
C.P.
Desert Rock
NEVADA
CALIFORNIA
NOTE-
INFINITE DOSE PLOTTED.


U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
INFINITE DOSE - SHOT NO. 5 - HORNET
12 MAR. 1955 — H-HOUR 0520 PST
MASON & HANGER
SILAS MASON CO. INC.
SK-SM 1092
DATA FROM GROUND SURVEY.
St. George
UTAH
ARIZONA
NEVADA
U.S. 91
U.S. 93
U.S. 95
Alamo
Glendale
Lake Mead
Las Vegas
Indian Springs
Mercury
Desert Rock
N. T. S.
C.P.
NEVADA
CALIF.
25 mr
100 mr
500 mr
1R
4R


U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
EFF. BIOL. DOSE - SHOT NO.5 - HORNET
12 MARCH 1955 - H-HOUR 0520 PST
MASON & HANGER
SILAS MASON CO. INC.
SK-SM 1094
DATA FROM GROUND SURVEY.
St. George
UTAH
ARIZONA
NEVADA
U.S. 91
U.S. 93
U.S. 95
10 mr
25 mr
100 mr
Glendale
Alamo
Lake Mead
Las Vegas
Indian Springs
Mercury
Desert Rock
N. T. S.
C.P.
NEVADA
CALIF.

Bee

Bee was a 500-foot tower detonation which was fired at 5:05 a. m. on March 22, 1955. The shot took place in test area 7 in Yucca Flat.

The airway closure pattern was as follows:

1. A circular area around Yucca Flat, with a radius of 60 nautical miles, was ordered closed at all altitudes from 4:45 a. m. to 5:30 a. m.
2. A sector as described below was ordered closed from 5:45 a. m. to 10:15 a. m. at altitudes from 17,000 to 40,000 feet. The boundaries of the sector were: From CP along 100° radius to LF 5745, then south to LD 4730, east to Phoenix, Ariz., then along north edge of airway Green 5 to FD 2740, and finally back to CP along 160° radius.
3. At 7:25 a. m. airway Amber 2 was closed at all altitudes within the above sector for 1 hour.
4. At 7:30 a. m. airway Red 15 was ordered closed at all altitudes between Amber 2 and Green 4 for 1 hour.
5. At 8:40 a. m. Amber 2 was opened at all altitudes.

The cloud was tracked by B–25, B–29, and sampler aircraft to a maximum distance of about 130 nautical miles on a general bearing of about 130°. The plot made from reports of these aircraft is shown on the accompanying map. The cloud stabilized at about 39,000 feet, and separated into several layers below the top altitude.

No D-day low-level terrain survey was made by the C–47 as ground parties were reporting fairly low intensities. On D-plus-one day, a survey was made to cover the areas inaccessible to ground parties. It was not possible to obtain reliable results from this survey because the cloud from Ess (detonated the day after Bee) drifted along virtually the same path as that from Bee, such that fall-out from both shots would be expected in the same areas.

Monitoring runs, which indicated activity substantially above background, were made on U. S. 93 between Las Vegas, Nev., and a point 30 miles southeast of Boulder City, Nev.; along U. S. 91 between a point 2 miles northeast of Nellis Air Force Base and the intersection of South Fifth Street (Las Vegas proper); in North Las Vegas, Nev.; in the northeast section of Las Vegas, Nev.; on the game preserve road north of U. S. 95; along the desert road north of Indian Springs, Nev.; and on several of the desert roads east of the Nevada test site.

The maximum effective biological dose for a populated area was 185 mr. at North Las Vegas, Nev. The maximum effective biological dose at a nonpopulated point was 26,400 mr. 4.7 miles south of Papoose Lake.

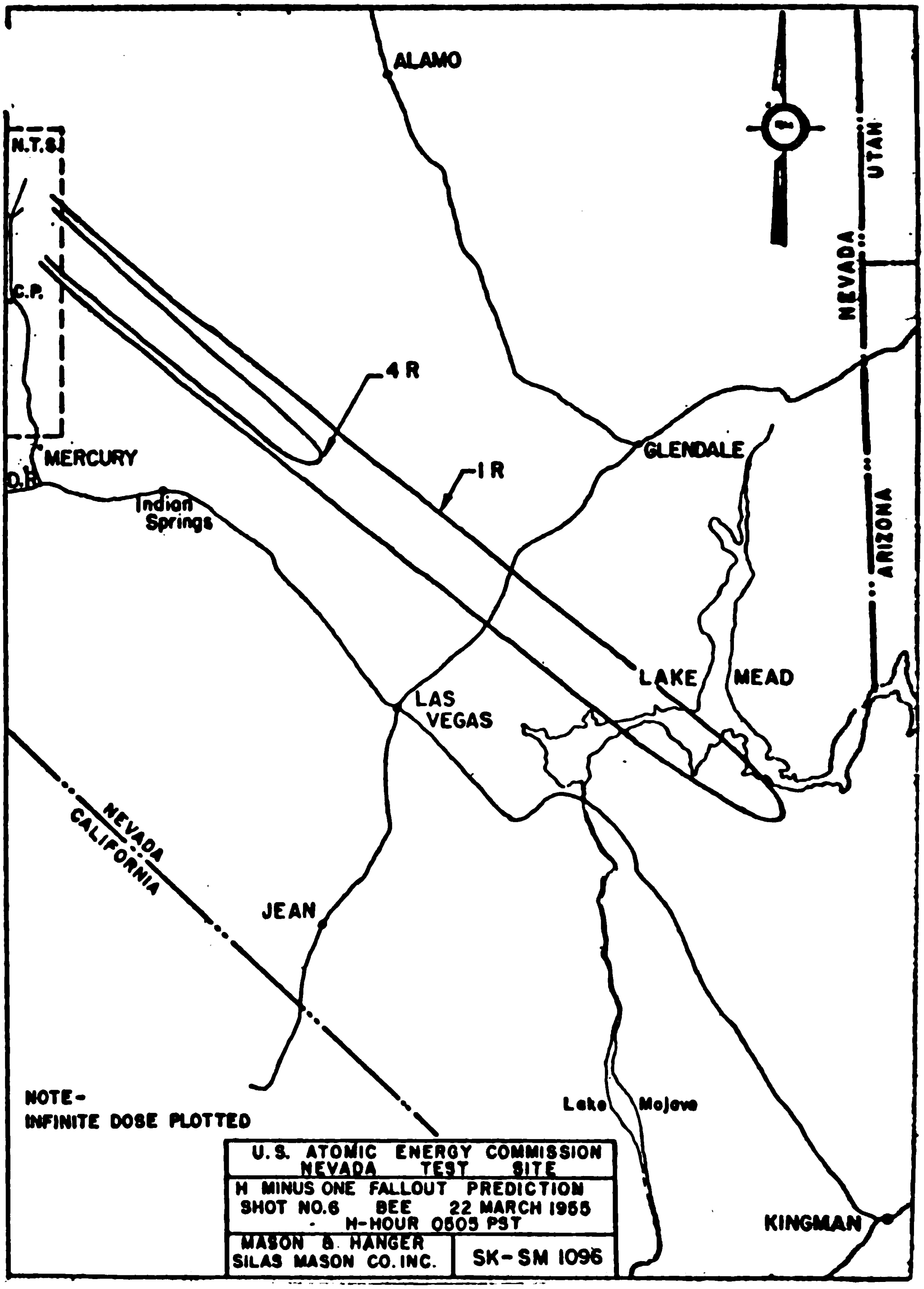
Approximately 170 individual monitoring readings above 0.1 mr./hr. were recorded.

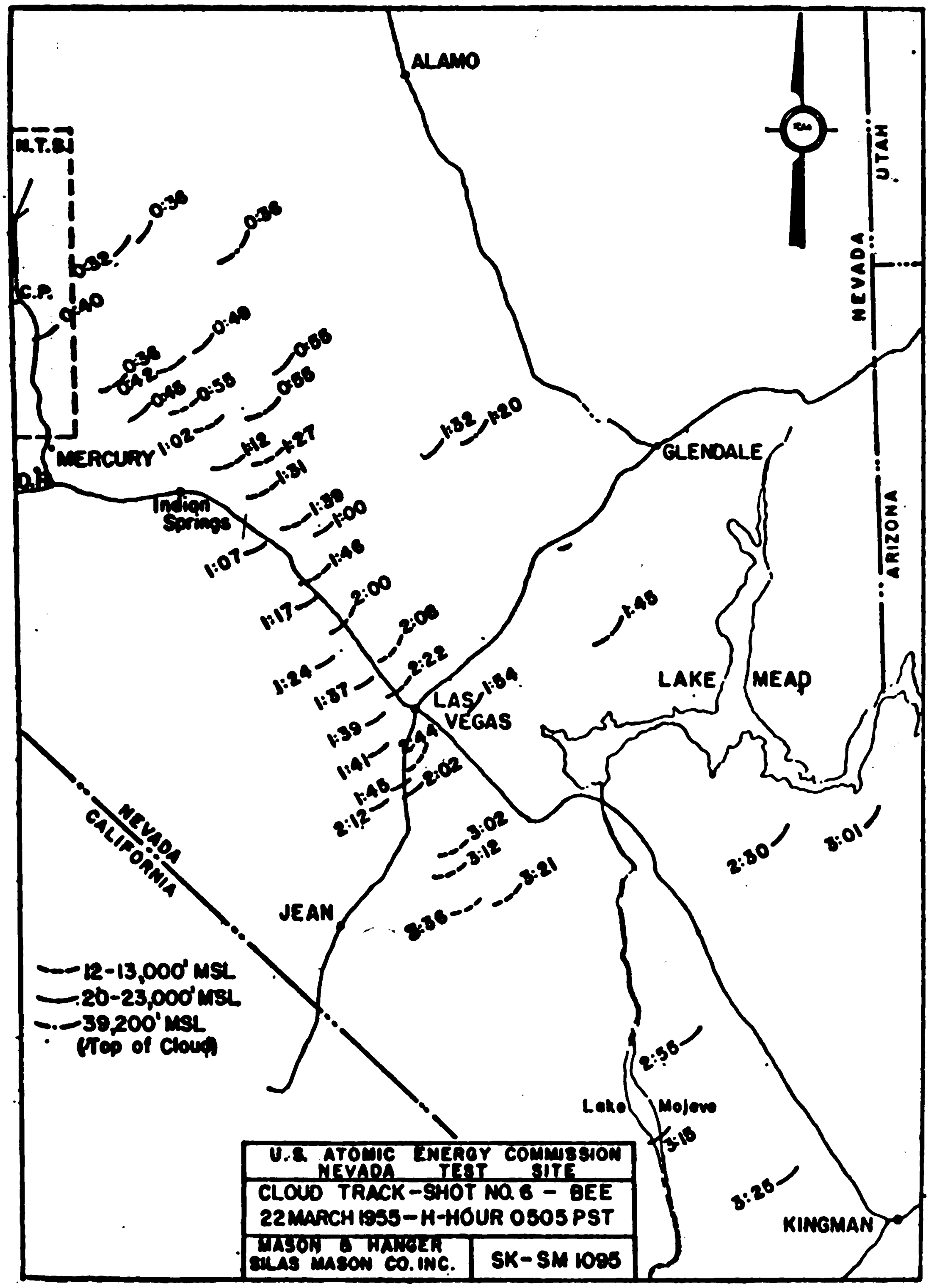
A comparison of the prediction map and the factual maps indicates rather poor agreement in direction and especially in magnitude. Fallout occurred south of the predicted path and the 1 r. infinite isodose contour extended out only about 20 percent of the predicted distance. It is apparent from the factual map that the 1 r. isodose contour did not intersect any major highways.

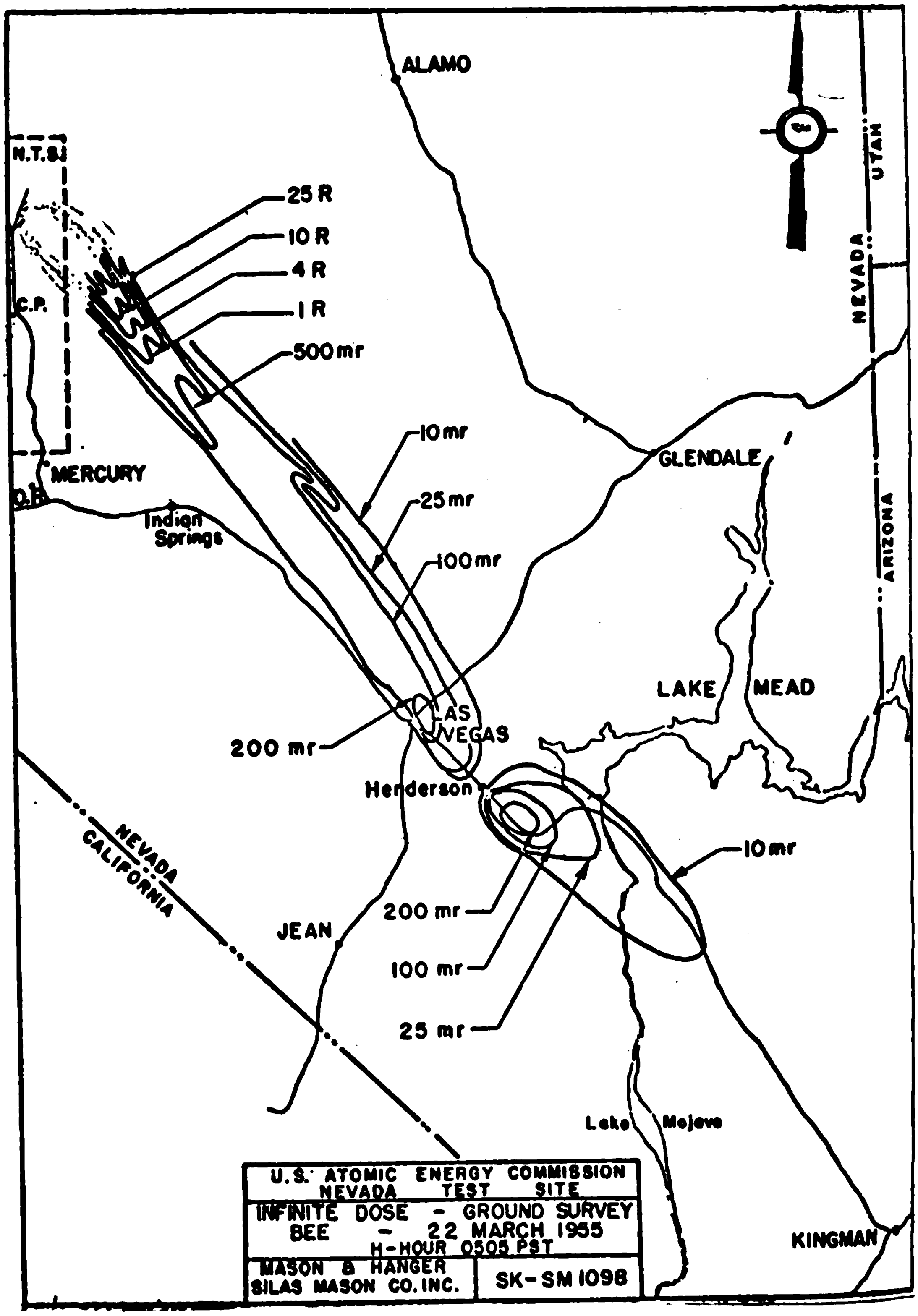
The maximum air radioactivity concentration measured was $3.5\times10^{-3}\mu c/m^3$, at Nellis Air Force Base, Nev. This represents the average air concentration for a 12-hour period starting at shot time.

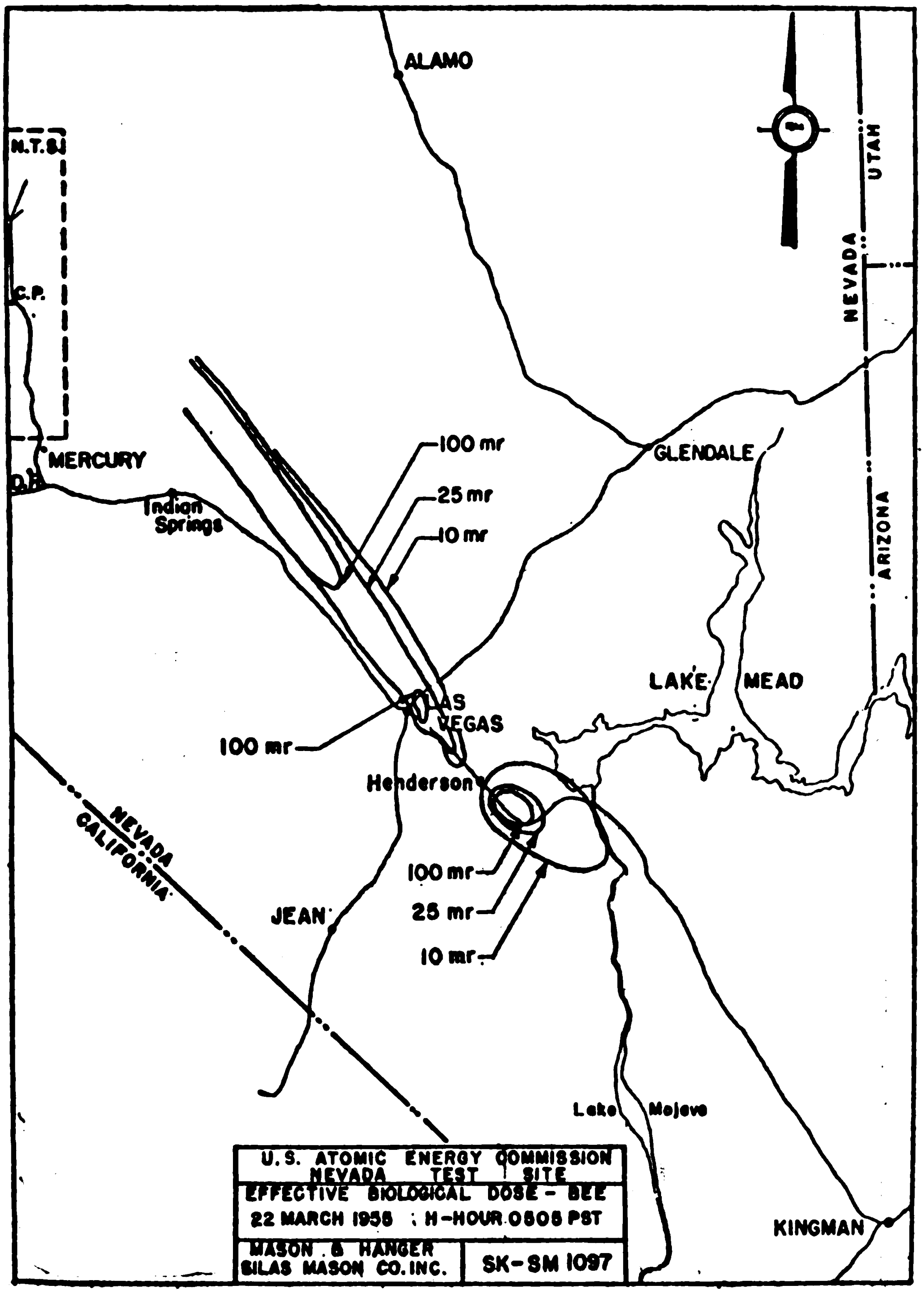
Bee: External gamma dose in populated areas and at selected nonpopulated points

Location	Time of instrument readings (H+hours)	Gamma ground level (mr./hr.)	Time of fallout (H+hours)	Effective biological dose (mr.)	Infinite dose (mr.)
Populated areas:					
Las Vegas, Nev	5.5	9.0	4.2	140	260
North Las Vegas, Nev	5.1	13.0	4.1	185	345
Nellis Air Force Base, Nev	6.4	1.2	4.1	23	42
Henderson, Nev	5.7	.5	4.8	8	15
Boulder City, Nev	7.3	4.0	5.2	83	156
Whitney, Nev	5.8	.5	4.5	8	15
Hoover Dam, Nev	9	.4	5.2	11	20
Nonpopulated points:					
U. S. 93–95, 3 miles south of Henderson, Nev	5.1	18	4.9	246	465
4.7 miles south of Papoose Lake	55.4	60	.54	26,400	42,110


ALAMO
N.T.S.
C.P.
UTAH
NEVADA
ARIZONA
4 R
1 R
MERCURY
D.R.
Indian Springs
GLENDALE
LAKE MEAD
LAS VEGAS
NEVADA
CALIFORNIA
JEAN
NOTE-
INFINITE DOSE PLOTTED
Lake Mojave
KINGMAN
U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
H MINUS ONE FALLOUT PREDICTION
SHOT NO.6 BEE 22 MARCH 1955
H-HOUR 0505 PST
MASON & HANGER
SILAS MASON CO. INC.
SK-SM 1096


ALAMO
N.T.S.
C.P.
MERCURY
D.B.
Indian Springs
GLENDALE
UTAH
NEVADA
ARIZONA
LAKE MEAD
LAS VEGAS
NEVADA
CALIFORNIA
JEAN
Lake Mojave
KINGMAN
0:36
0:32
0:36
0:40
0:49
0:56
0:36
0:42
0:46
0:55
0:56
1:02
1:12
1:27
1:32
1:20
1:31
1:39
1:00
1:07
1:46
1:17
2:00
2:06
1:24
2:22
1:37
1:54
1:45
1:39
1:41
2:44
2:02
1:45
2:12
3:02
3:12
3:21
3:36
2:30
3:01
2:56
3:15
3:25
12-13,000' MSL
20-23,000' MSL
39,200' MSL
(Top of Cloud)
U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
CLOUD TRACK-SHOT NO. 6 - BEE
22 MARCH 1955-H-HOUR 0505 PST
MASON & HANGER
SILAS MASON CO. INC.
SK-SM 1095


ALAMO
N.T.S.
25 R
10 R
4 R
1 R
C.P.
500mr
10mr
MERCURY
Indian Springs
25mr
100mr
GLENDALE
UTAH
NEVADA
ARIZONA
LAKE
MEAD
LAS VEGAS
200 mr
Henderson
10mr
NEVADA
CALIFORNIA
200 mr
JEAN
100 mr
25 mr
Lake Mojave
KINGMAN
U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
INFINITE DOSE - GROUND SURVEY
BEE - 22 MARCH 1955
H-HOUR 0505 PST
MASON & HANGER
SILAS MASON CO. INC.
SK-SM 1098



ALAMO
N.T.S.
C.P.
MERCURY
Indian Springs
GLENDALE
UTAH
NEVADA
ARIZONA
100 mr
25 mr
10 mr
LAKE MEAD
LAS VEGAS
100 mr
Henderson
NEVADA
CALIFORNIA
100 mr
25 mr
10 mr
JEAN
Lake Mojave
KINGMAN
U. S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
EFFECTIVE BIOLOGICAL DOSE - BEE
22 MARCH 1955 : H-HOUR 0505 PST
MASON & HANGER
SILAS MASON CO. INC.
SK-SM 1097

Ess

Ess was an underground detonation which was fired at 12 p. m. on March 23, 1955. The shot took place in test area 10 in Yucca Flat.

No airway closure pattern was established for Ess.

The cloud was tracked as shown on the accompanying map from H plus 35 minutes to H plus 4 hours and 20 minutes. Tracking was accomplished between 10,000 and 13,000 feet by a B-25 type aircraft.

A low-level terrain survey was flown from H plus 3 hours to H plus 5 hours by 1 C-47. The results of this survey are shown on the accompanying map.

Monitoring runs, which indicated activity substantially above background, were made on U. S. 93 between a point 21 miles south of Alamo, Nev., and Glendale, Nev.; on the desert road north of Indian Springs, Nev.; and along several of the desert roads east of the Nevada test site.

The maximum effective biological dose for a populated area was 30 mr. at Beaver Dam, Ariz. The maximum effective biological dose at a nonpopulated point was 2,510 mr. 22 miles north of Indian Springs, Nev.

Approximately 105 individual monitoring readings above 0.1 mr./hr. were recorded.

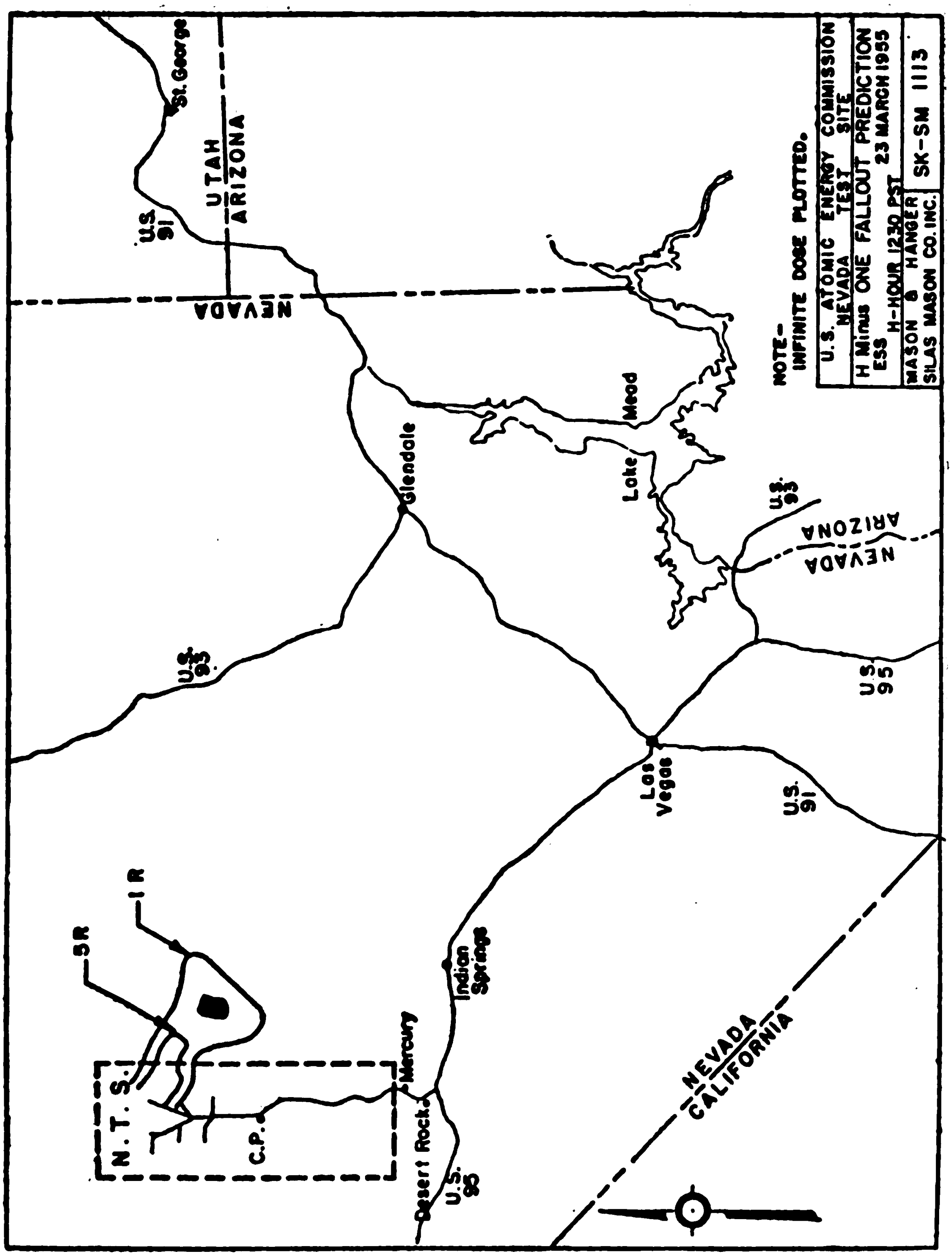
A comparison of the prediction map and the factual maps indicates good agreement in direction, but the 1 r. isodose contour was at least twice as long as was predicted.

The low-level terrain survey map shows roughly twice the infinite doses that are plotted from ground monitoring results. The leading edge of the cloud did not cross the eastern boundary of the bombing and gunnery range until approximately H plus 4 hours. The haze from the cloud could still be seen in the Valley to the east and northeast of Indian Springs, Nev., at H plus 5 hours. The higher dose indicated by the low-level terrain survey are, therefore, probably due to radiation from that part of the cloud still in the valley when the survey was made. The ground monitoring plot also indicates extensive shear and the effects of terrain features on fallout pattern. It is apparent from the maps that the 1 r. isodose contour did not intersect any major highways.

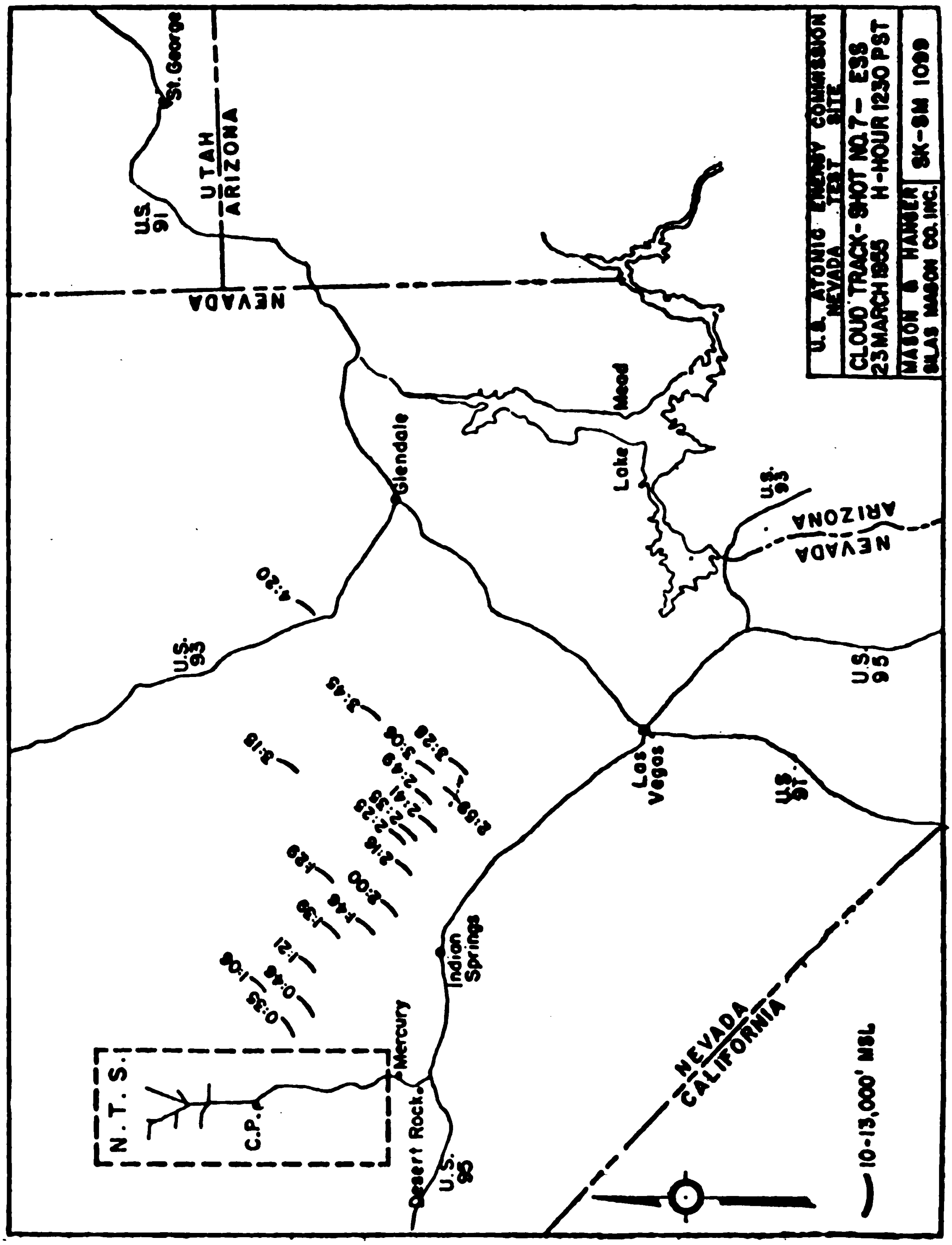
The maximum air radioactivity concentration measured was $4.5 \times 10^{-3} \mu c/m^3$, at Mesquite, Nev. This represents the average air concentration for a 43-hour period starting 1.5 hours after detonation.

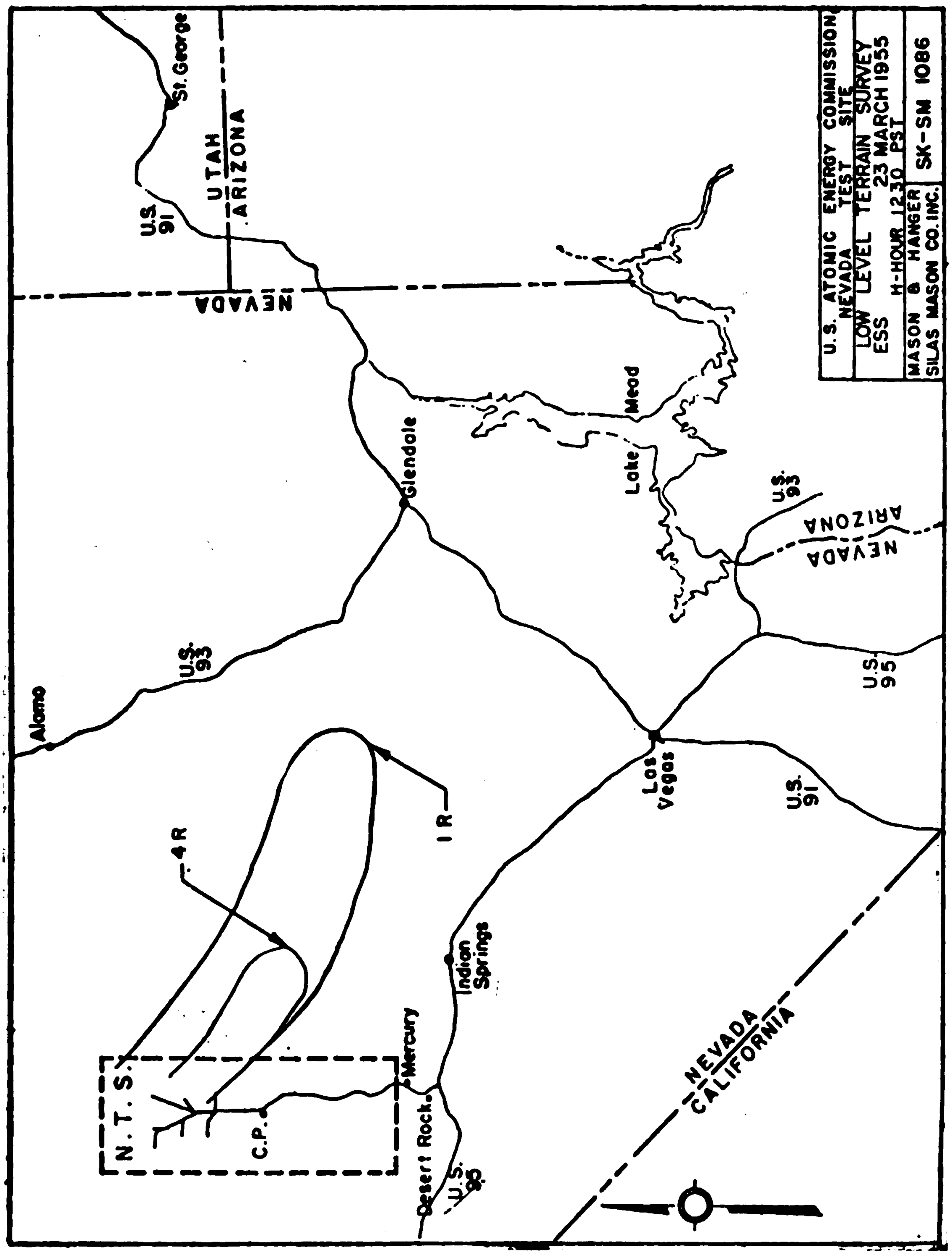
Ess: External gamma dose in populated areas and at selected nonpopulated points

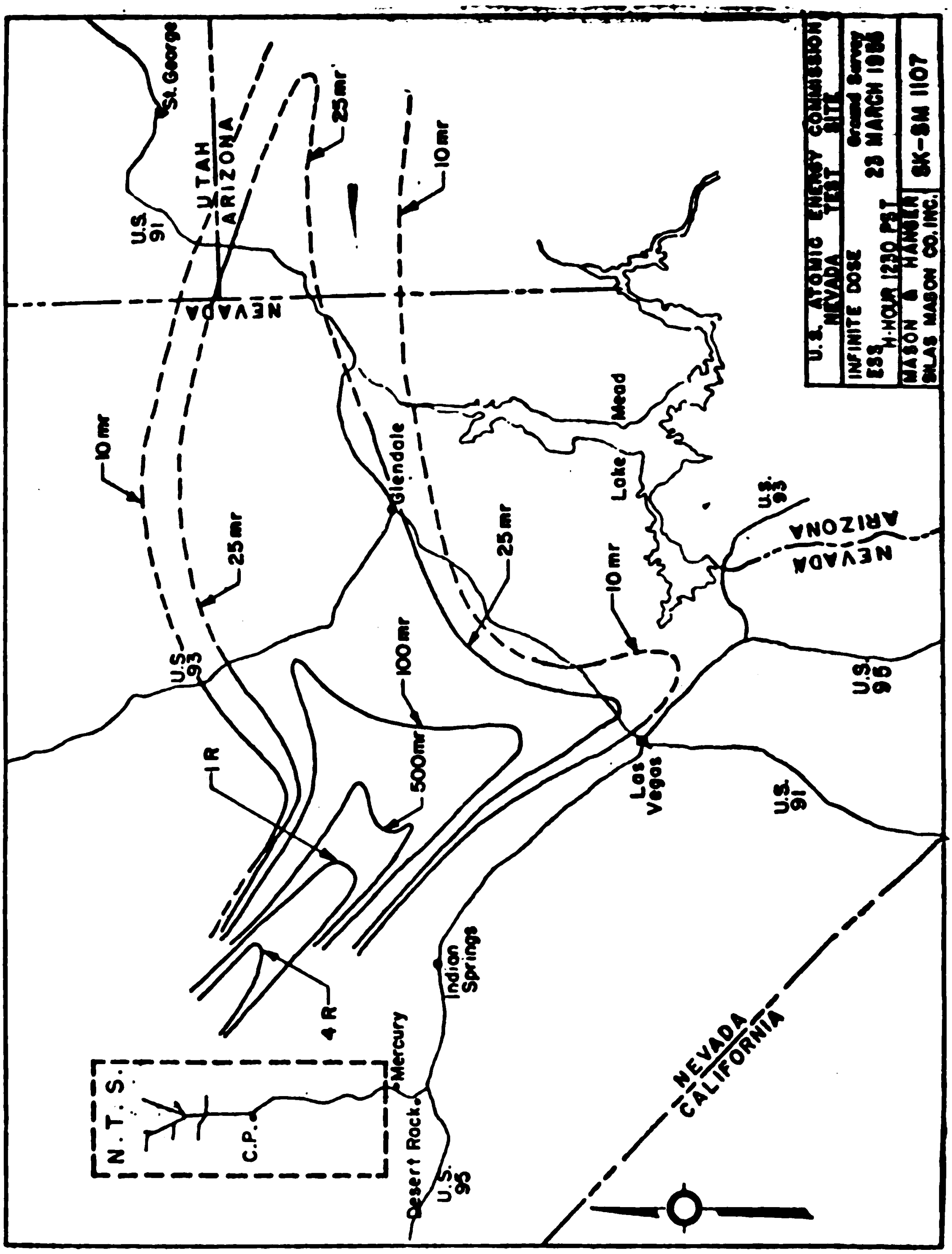
Location	Time of instrument reading (H+hours)	Gamma ground level (mr./hr.)	Time of fallout (H+hours)	Effective biological dose (mr.)	Infinite dose (mr.)
Populated areas:					
Nellis Air Force Base, Nev	3.5	0.8	3.5	8	14
Lake Mead Base, Nev	4.0	1.5	3.5	16	30
North Las Vegas, Nev	6.5	.3	3.5	7	12
Glendale, Nev	7.2	1.5	6.0	25	45
Moapa, Nev	20.9	.2	6.0	14	27
Beaver Dam, Ariz	23.6	.4	10.0	30	60
Nonpopulated points:					
U. S. 93, 38 miles south of Alamo, Nev	6.3	3.0	6.0	51	100
22 miles north of Indian Springs, Nev	5.3	140.0	2.0	2,510	4,400

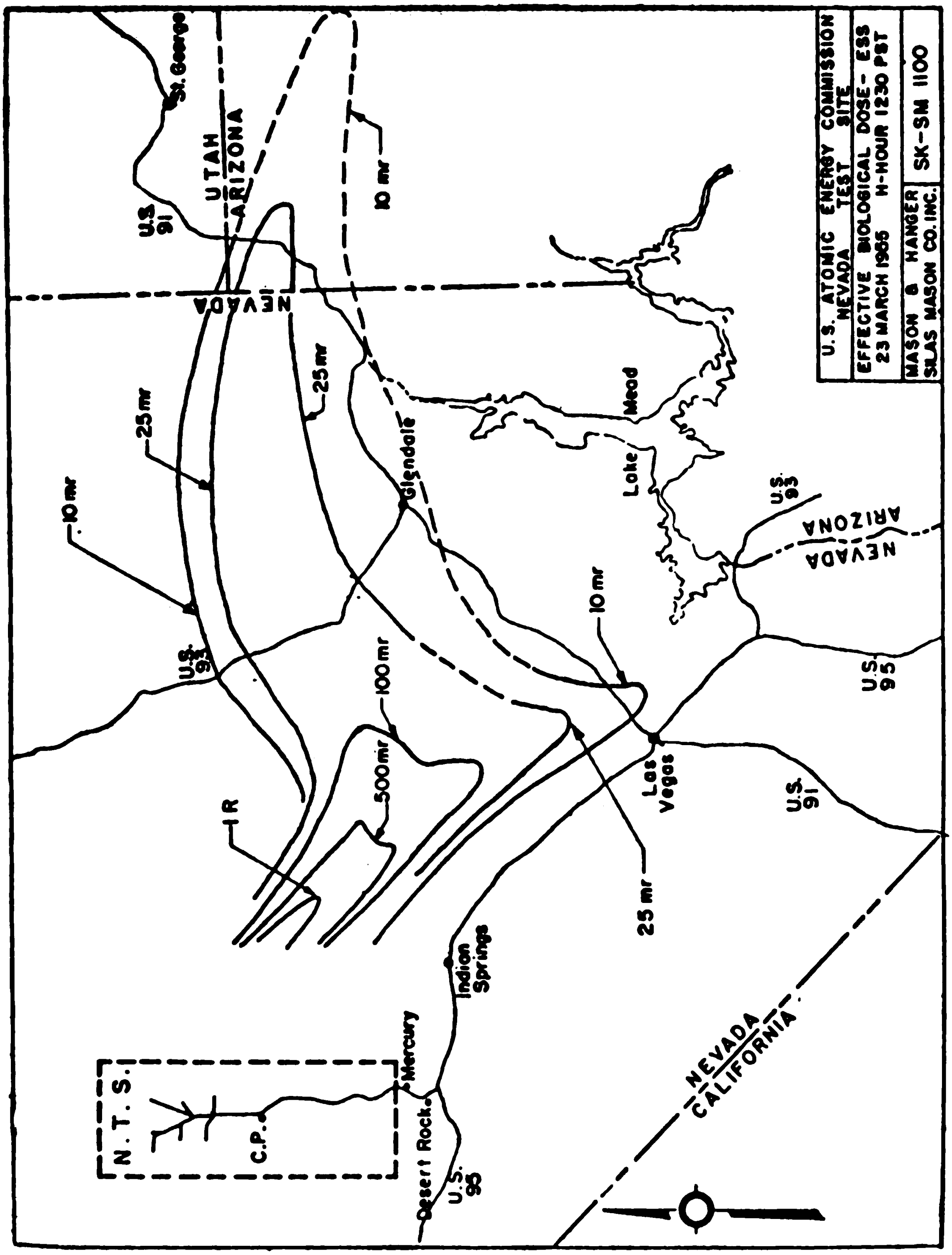


U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
H Minus ONE FALLOUT PREDICTION
ESS
H-HOUR 1230 PST 23 MARCH 1955
MASON & HANGER
SILAS MASON CO. INC.
SK-SM 1113
NOTE-
INFINITE DOSE PLOTTED.
St. George
UTAH
ARIZONA
NEVADA
U.S. 91
Glendale
Lake Mead
U.S. 93
ARIZONA
NEVADA
U.S. 95
U.S. 93
Las Vegas
U.S. 91
Indian Springs
Mercury
Desert Rock
U.S. 95
N. T. S.
C.P.
5R
1R
NEVADA
CALIFORNIA


U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
CLOUD TRACK-SHOT NO. 7 — ESS
23 MARCH 1955 H-HOUR 1230 PST
MASON & HANGER
SILAS MASON CO. INC.
SK-SM 1099
St. George
UTAH
ARIZONA
NEVADA
U.S. 91
Glendale
Lake Mead
U.S. 93
Las Vegas
U.S. 95
Indian Springs
Mercury
Desert Rock
N. T. S.
C.P.
NEVADA
CALIFORNIA
10-13,000' MSL
0:35
0:48
1:08
1:21
1:39
1:48
2:00
2:16
2:25
2:35
2:41
2:49
3:08
3:28
3:45
4:20


U. S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
LOW LEVEL TERRAIN SURVEY
ESS 23 MARCH 1955
H-HOUR 1230 PST
MASON & HANGER
SILAS MASON CO. INC.
SK-SM 1086
St. George
UTAH
ARIZONA
U.S. 91
NEVADA
Lake Mead
Glendale
U.S. 93
Alamo
Las Vegas
U.S. 95
U.S. 91
4 R
I R
Indian Springs
Mercury
N. T. S.
C.P.
Desert Rock
U.S. 95
NEVADA
CALIFORNIA


U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
INFINITE DOSE
ESS
H-HOUR 1230 PST
Ground Survey
MASON & HANGER
SILAS MASON CO. INC.
SK-SM 1107
St. George
U.S. 91
UTAH
ARIZONA
NEVADA
25 mr
10 mr
Lake Mead
Glendale
U.S. 93
25 mr
10 mr
25 mr
10 mr
U.S. 93
ARIZONA
NEVADA
U.S. 95
100 mr
500 mr
1 R
4 R
Las Vegas
U.S. 91
Indian Springs
Mercury
Desert Rock
U.S. 95
N. T. S.
C.P.
NEVADA
CALIFORNIA


U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
EFFECTIVE BIOLOGICAL DOSE - ESS
23 MARCH 1955 H-HOUR 1230 PST
MASON & HANGER
SILAS MASON CO. INC.
SK-SM 1100
St. George
UTAH
ARIZONA
NEVADA
U.S. 91
U.S. 93
U.S. 95
10 mr
25 mr
100 mr
500 mr
1 R
Glendale
Lake Mead
Las Vegas
Indian Springs
Mercury
Desert Rock
N. T. S.
C.P.
NEVADA
CALIFORNIA

Apple

Apple was a 500-foot tower detonation which was fired at 4:55 a. m. on March 29, 1955. The shot took place in test area 4 in Yucca Flat.

The airway closure pattern was as follows:

1. A circular area around Yucca Flat, with a radius of 60 nautical miles was closed at all altitudes from 4:30 a. m. to 2 p. m. The extended closure time was necessary since a second shot, Wasp Prime, was scheduled for approximately 10 a. m.
2. A sector, with radii at 70° and 130° extending to the Utah-Colorado and Arizona-New Mexico borders, was closed from 22,000 feet and above from 6 a. m. to 1 p. m.
3. At 6:20 a. m., the closed altitudes were changed to read 18,000 to 33,000 feet, inclusive.
4. At 9:10 a. m., the 130° radius was moved to 110°, extending to the north edge of airway Green 4, and along this path to the Arizona-New Mexico border.

The cloud was tracked by one B-50 and one B-25 aircraft at the levels of 21,000 and 13,000 feet, respectively, with additional reports from sampler aircraft. The maximum distance to which the cloud was tracked was 168 nautical miles on a bearing of approximately 90°. At the lower level, the general bearing was between 60° and 70°. Maximum cloud height observed was 31,000 feet.

A low-level terrain survey was flown by one C-47 starting at about H plus 6 hours and 35 minutes. Results are plotted on the accompanying map.

Monitoring runs, which indicated activity substantially above background, were made on U. S. 91 between St. George, Utah, and Cedar City, Utah; along U. S. 93 between Alamo, Nev., and Pioche, Nev.; on Utah 18 between Central, Utah, and Beryl, Utah; along Utah 56 west of Cedar City, Utah, and continuing on Nevada 25 to the junction with U. S. 93; along Nevada 25 in the vicinity of Lincoln Mine, Nevada; on the desert road north of Indian Springs, Nev.; and along several of the desert roads north and east of the Nevada test site.

The maximum effective biological dose for a populated area was 1,300 mr. at Alamo, Nev. The maximum effective biological dose at a nonpopulated point was 6,500 mr., 4.3 miles south of Groom Lake on Kelly Mine Road.

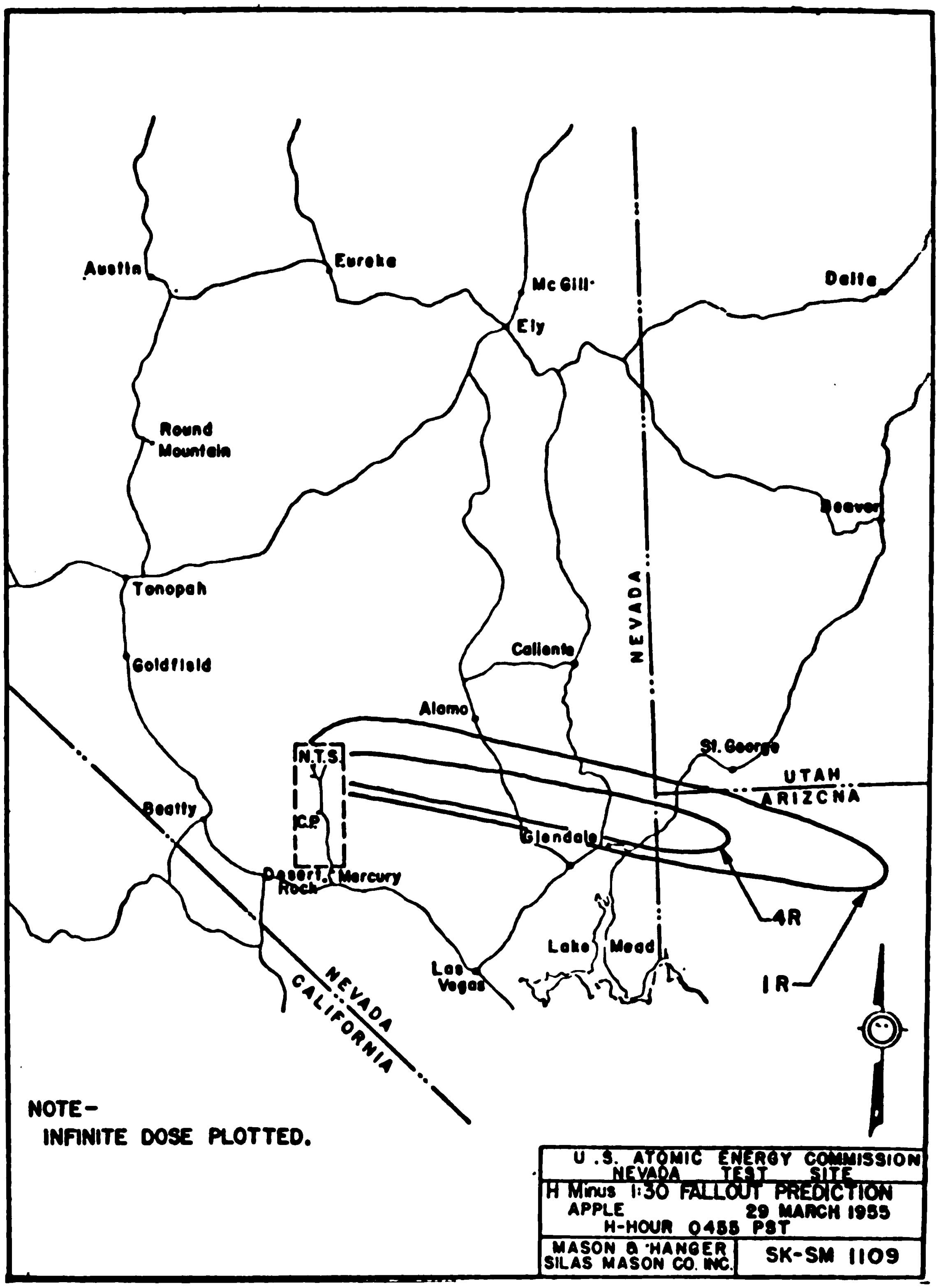
Approximately 395 individual monitoring readings above 0.1 mr./hr. were recorded.

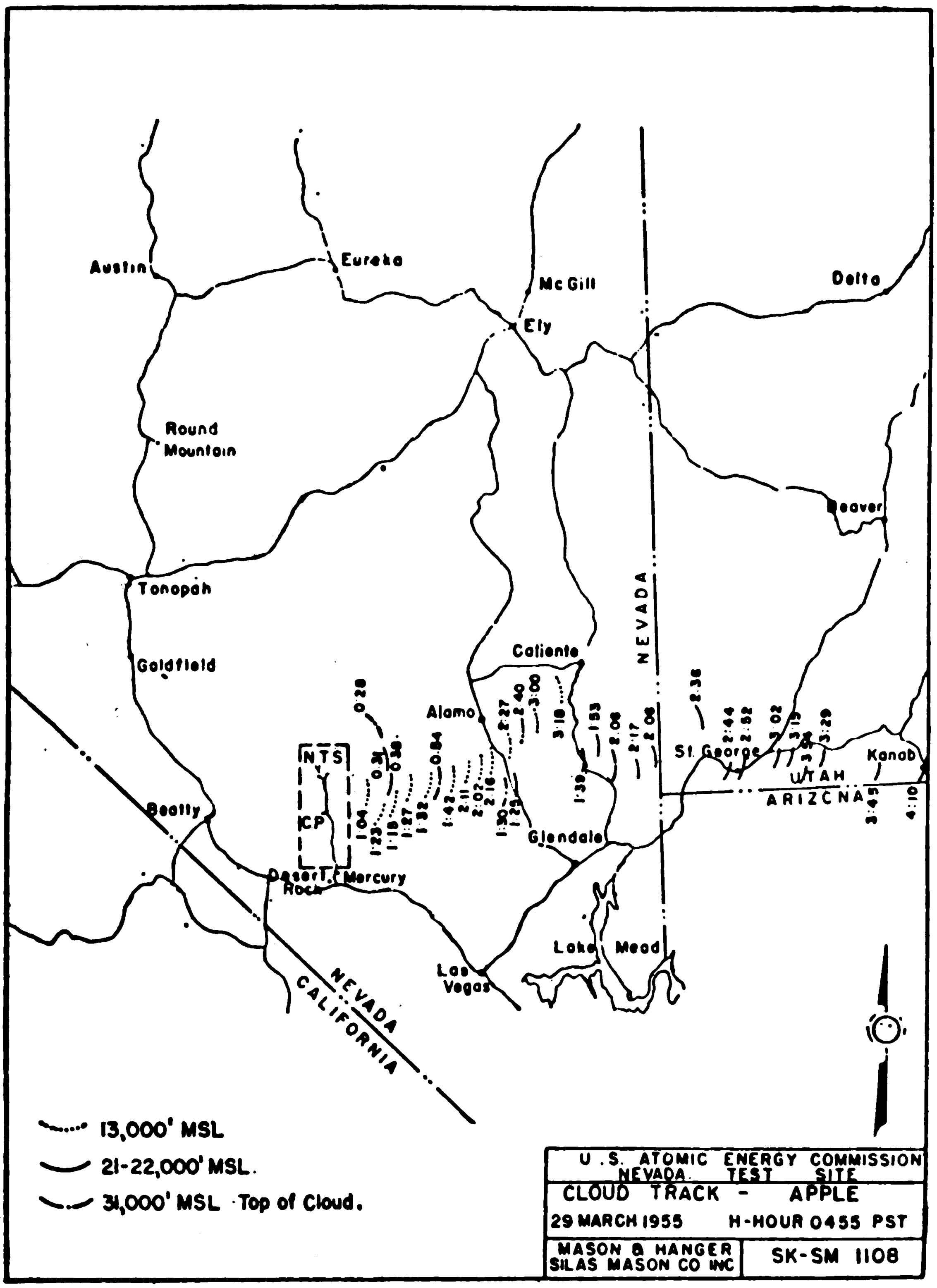
A comparison of the prediction map and the factual maps indicates that the predicted direction was off by 20° and that the 1 r. infinite isodose contour extended only about one-third of the predicted distance. The low-level terrain survey map is in good agreement with the map depicting ground monitoring results. The 1 r. infinite dose contour crossed U. S. 93 at Alamo, Nev.

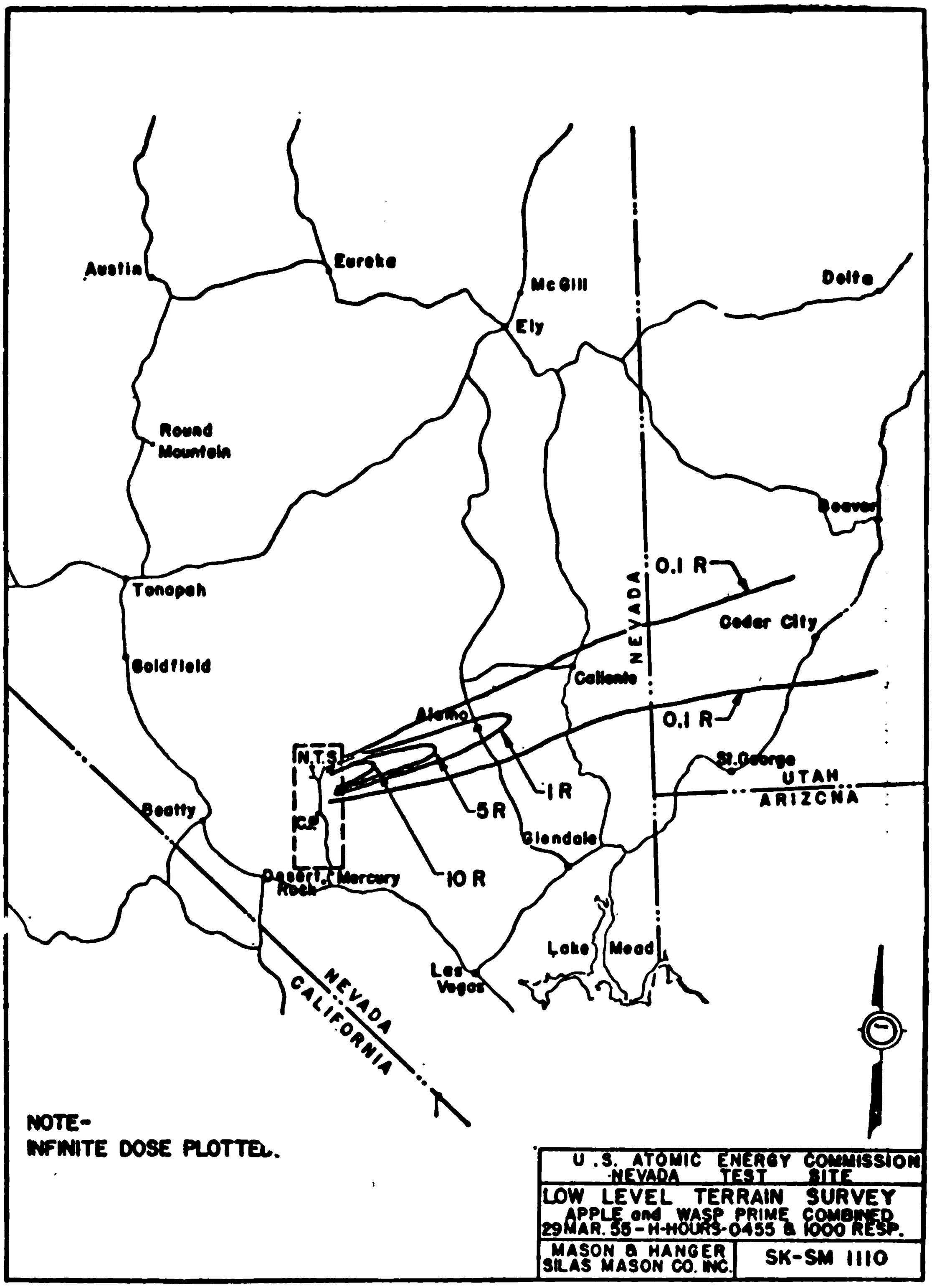
The maximum air radioactivity concentration measured was $4.0\times10^{-3}\mu c/m^3$, at Alamo, Nev. This represents the average air concentration for a 28-hour period starting at shot time.

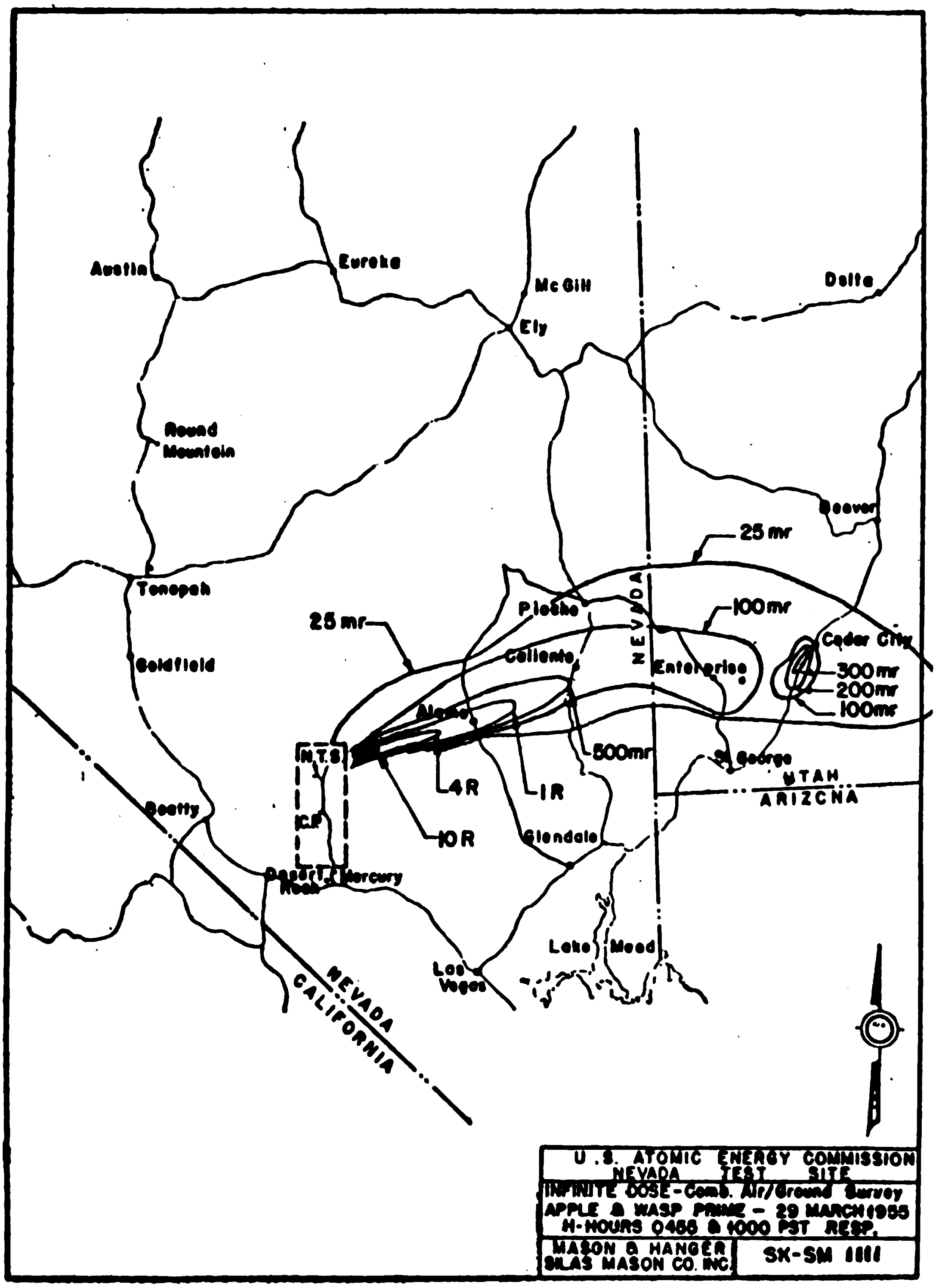
Apple: External gamma dose in populated areas and at selected nonpopulated points

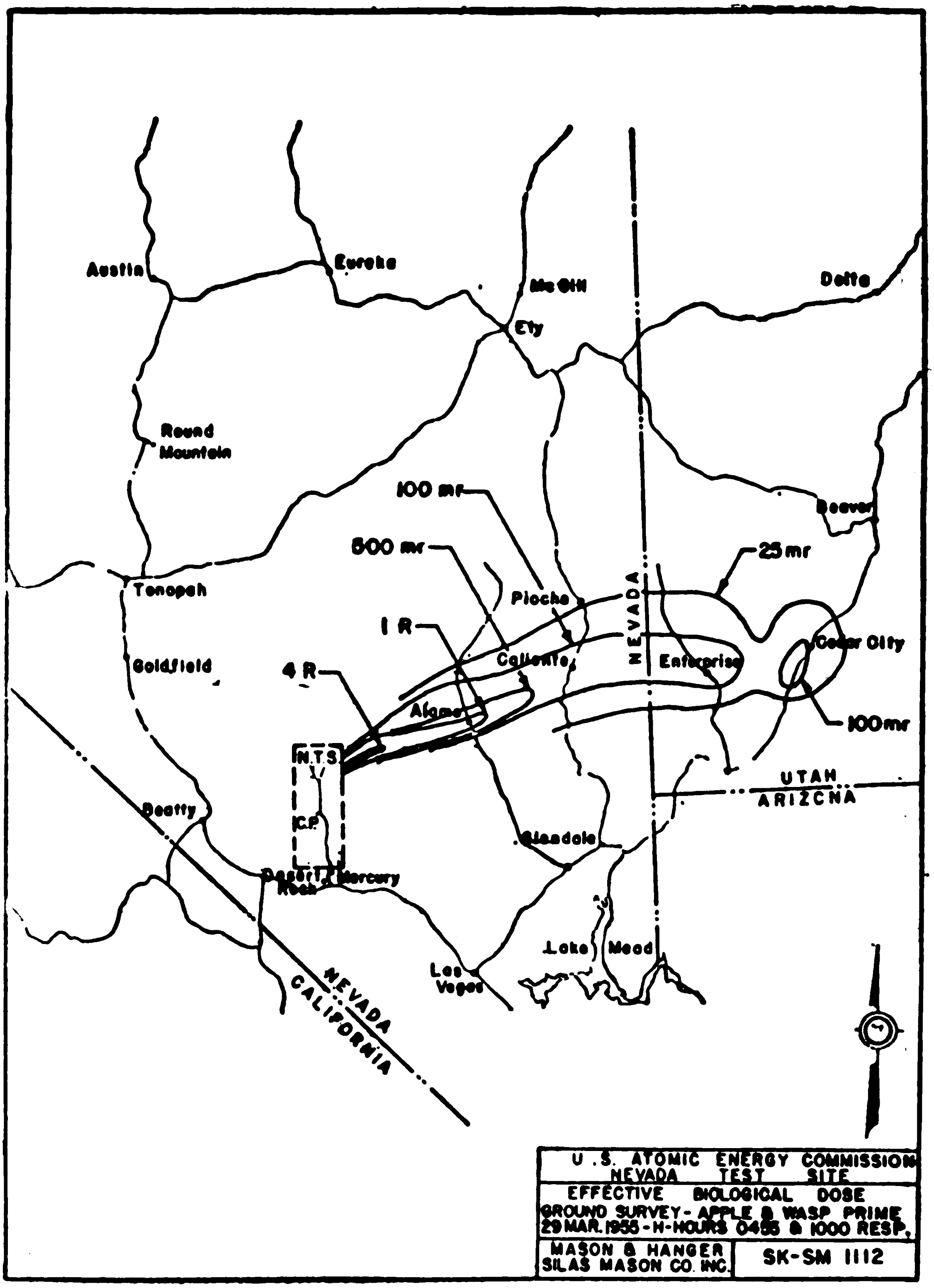
Location	Time of instrument reading (H+hours)	Gamma ground level (mr./hr.)	Time of fallout (H+hours)	Effective biological dose (mr.)	Infinite dose (mr.)
Populated areas:					
Lincoln Mine, Nev	6.1	0.5	2.3	10	19
Alamo, Nev	2.8	160.0	2.6	1,300	2,300
Crystal Springs, Nev	9.4	1.5	2.7	50	91
Hiko, Nev	12.2	1.4	2.7	63	110
Pioche, Nev	5.5	1.0	4.6	15	30
Panaca, Nev	5.9	2.5	4.6	41	80
Modena, Utah	6.7	2.0	5.5	37	70
Ursine, Nev	12.1	.3	5.1	10	22
Caliente, Nev	4.9	9.0	4.1	120	230
Beryl Junction, Utah	6.5	5.0	5.9	86	170
Enterprise, Utah	6.8	9.5	5.8	180	340
New Harmony, Utah	5.5	4.0	4.9	59	110
Kanarraville, Utah	5.7	10.0	5.1	150	290
Hamilton Fort, Utah	5.9	6.0	5.3	95	180
Cedar City, Utah	6.0	3.0	5.4	48	92
Newcastle, Utah	6.7	10.0	6.1	175	340
Ely, Nev	10.4	.12	6.7	4	7
Currant, Nev	9.5	.10	5.0	3	5
Orderville, Utah	34.5	.16	7.9	19	37
Glendale, Utah	34.6	.16	8.3	19	37
Alton, Utah	35.0	.16	8.3	19	37
Nonpopulated points:					
U. S. 93, 1 mile south of Alamo, Nev	28.2	12.0	2.7	1,500	2,700
4.3 miles south of Groom Lake	54.6	18.0	.9	6,500	11,000


Austin
Eureka
McGill
Ely
Delta
Round Mountain
Beaver
Tonopah
Goldfield
Caliente
NEVADA
Alamo
N.T.S.
C.P.
St. George
UTAH
ARIZONA
Beatty
Glendale
Desert Rock
Mercury
4R
Lake Mead
Las Vegas
IR
NEVADA
CALIFORNIA
NOTE-
INFINITE DOSE PLOTTED.
U. S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
H Minus 1:30 FALLOUT PREDICTION
APPLE 29 MARCH 1955
H-HOUR 0455 PST
MASON & HANGER
SILAS MASON CO. INC.
SK-SM 1109


Austin
Eureka
McGill
Ely
Delta
Round Mountain
Beaver
Tonopah
Goldfield
Caliente
NEVADA
Alamo
NTS
CP
St. George
Kanab
UTAH
Beatty
Glendale
Desert Rock
Mercury
Lake Mead
Las Vegas
NEVADA
CALIFORNIA
13,000' MSL
21-22,000' MSL.
31,000' MSL Top of Cloud.
U. S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
CLOUD TRACK - APPLE
29 MARCH 1955 H-HOUR 0455 PST
MASON & HANGER
SILAS MASON CO INC
SK-SM 1108


Austin
Eureka
McGill
Ely
Delta
Round Mountain
Beaver
Tonopah
0.1 R
Cedar City
Goldfield
NEVADA
Caliente
Alamo
0.1 R
N.T.S.
St.George
UTAH
ARIZONA
1 R
5 R
Beatty
C.P.
Glendale
Desert Rock
Mercury
10 R
Lake Mead
Las Vegas
NEVADA
CALIFORNIA
NOTE-
INFINITE DOSE PLOTTED.
U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
LOW LEVEL TERRAIN SURVEY
APPLE and WASP PRIME COMBINED
29 MAR. 55 - H-HOURS-0455 & 1000 RESP.
MASON & HANGER
SILAS MASON CO. INC.
SK-SM 1110


Austin
Eureka
McGill
Ely
Delta
Round Mountain
Beaver
25 mr
Tonopah
Pioche
100mr
25 mr
NEVADA
Cedar City
Goldfield
Caliente
Enterprise
300mr
200mr
100mr
Alamo
500mr
N.T.S.
St George
UTAH
ARIZONA
4R
1R
Beatty
C.P.
10 R
Glendale
Desert Rock
Mercury
Lake Mead
Las Vegas
NEVADA
CALIFORNIA
U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
INFINITE DOSE-Comb. Air/Ground Survey
APPLE & WASP PRIME - 29 MARCH 1955
H-HOURS 0455 & 1000 PST RESP.
MASON & HANGER
SILAS MASON CO. INC.
SX-SM 1111



Wasp Prime

Wasp Prime was an airdrop which was detonated at 10 a. m. on March 29, 1955. The shot took place in test area 7 in Yucca Flat.

The airway closure pattern was as follows:

1. A circular area around Yucca Flat, with a radius of 60 nautical miles, was ordered closed at all altitudes from 4:30 a. m. to 2 p. m. This was in conjunction with the flash circle for Apple.

2. A sector, with radii at 50° and 110°, length of radius 150 nautical miles, was ordered closed from 15,000 to 35,000 feet from 1 a. m. to 4 p. m.

3. At 10:30 a. m., the flash circle was opened between 110° and 360°. The end closure time on the sector and remaining part of the circle was changed to 1 p. m.

4. At 10:55 a. m., the lower closed altitude was raised from 15,000 to 18,000 feet.

A C-45 aircraft was assigned to track the cloud as the B-25 used earlier in the day for Apple was contaminated. The aircraft developed engine trouble and aborted the mission. A second C-45 was dispatched and tracked the cloud at 10,000 feet. Normal procedure could not be followed since the C-45 was not capable of flying at sufficiently high altitudes. In place of normal procedure, the cloud was tracked visually from below by the tracking aircraft. Additional reports were submitted by sampler aircraft. At low levels, the direction of the cloud track was along a bearing of 55° to 60°, while at higher levels, the approximate bearing was 74°. The maximum distance to which the track was followed was about 70 nautical miles.

No separate monitoring, either air or ground, was conducted for this detonation for two reasons. First, no fallout was expected and, secondly, as the cloud tracks were essentially the same in direction, any fallout would be determined by normal operational monitoring for Apple. Thus, the low level terrain survey and the ground monitoring maps for Apple are labeled "Apple and Wasp Prime Combined."

HA

HA was an air detonation which was fired at 10 a. m. on April 6, 1955, at an altitude of approximately 36,000 feet. The shot took place over Yucca Flat.

The airway closure pattern was as follows:

1. A circular area around Yucca Flat, with a radius of 60 nautical miles, was ordered closed at all altitudes from 8:30 to 1 p. m.

2. A sector with a radii at 110° and 180°, length of radius 150 nautical miles, was ordered closed from 25,000 feet up from 10 a. m. to 1 p. m.

3. At 11 a. m., all restrictions were removed.

Due to the height of the detonation, no regular cloud-tracking missions were flown. At 10:12 a. m. the cloud height was estimated by the sampler control aircraft to be 55,000 to 60,000 feet. Later data, at 10:20 a. m., indicated a drop to 45,000 to 47,000 feet.

No low level terrain survey missions were flown as no fallout was reported from ground monitoring teams.

Monitoring runs, made in the off-site area, indicated only background.

The only air radioactivity concentration measured in excess of $10^{-4}\mu c/m^3$ was $1.35\times10^{-4}\mu c/m^3$, at Lincoln Mine, Nev. This represents the average air concentration for a 24-hour period starting at shot time.

Post

Post was a 300-foot tower detonation which was fired at 4:30 a. m. on April 9, 1955. The shot took place in test area 9 in Yucca Flat.

The airway closure pattern was as follows:

1. A circular area around Yucca Flat, with a radius of 60 nautical miles, was ordered closed at all altitudes from 4 a. m. to 11:30 a. m. The extended closure time was due to the scheduling of another detonation, Met, later in the morning.

2. At 6:10 a. m., closure time on the flash circle was extended to 2 p. m. due to a delay in possible firing of Met.

3. At 8:10 a. m., closure time was cut back to 9 a. m. due to cancellation of Met.

The cloud was tracked by 1 B-25 aircraft flying at 13,000 feet, with additional reports coming from sampler aircraft. Maximum cloud height observed was 15,000 feet, with subsequent settling to 14,500 feet. The cloud was tracked to a maximum distance of 36 nautical miles at a bearing of approximately 165° from the command post. The plot of the cloud track is shown on the accompanying map.

A low level terrain survey was made by 1 C-47 aircraft from approximately H plus 5 hours to H plus 7 hours and 15 minutes. The survey indicated no significant off-site contamination.

Monitoring runs, which indicated activity substantially above background, were made on Mercury Road; along U. S. 95 between Lathrop Wells, Nev., and Indian Springs, Nev. on Nevada 16 between U. S. 95 and U. S. 91; and on the desert roads north and east of the Nevada test site.

The maximum effective biological dose for a populated area was 47 mr. at Camp Desert Rock, Nev. The maximum effective biological dose at a nonpopulated point was 162 mr., 3.5 miles south of Papoose Lake.

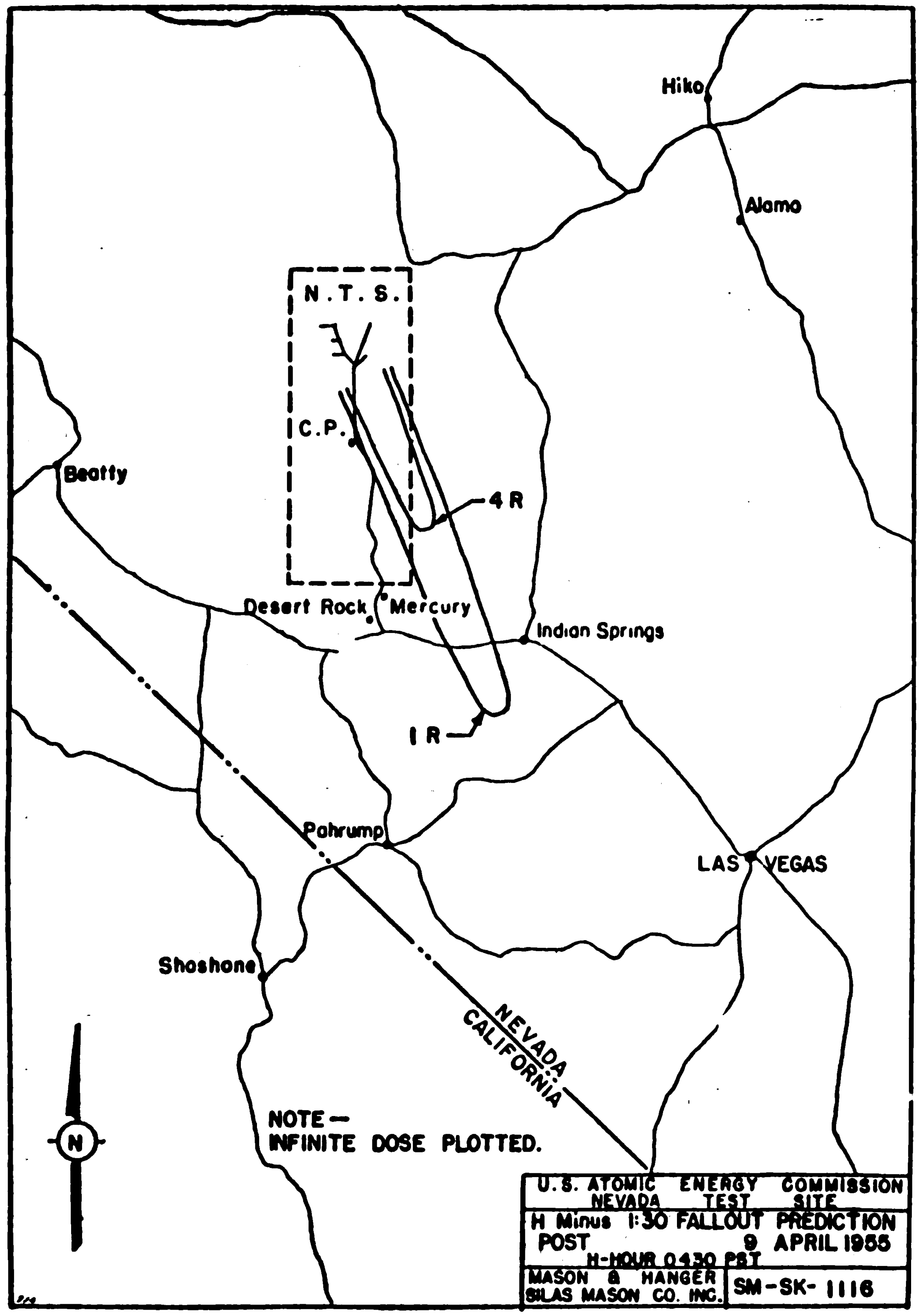
Approximately 75 individual monitoring readings above 0.1 mr/hr. were recorded.

The ground survey map indicates extensive scattering of fallout in several directions. An interesting point is the presence of fallout to the northeast, although the cloud was tracked in a southerly direction. Only very light fallout occurred outside the Nevada test site.

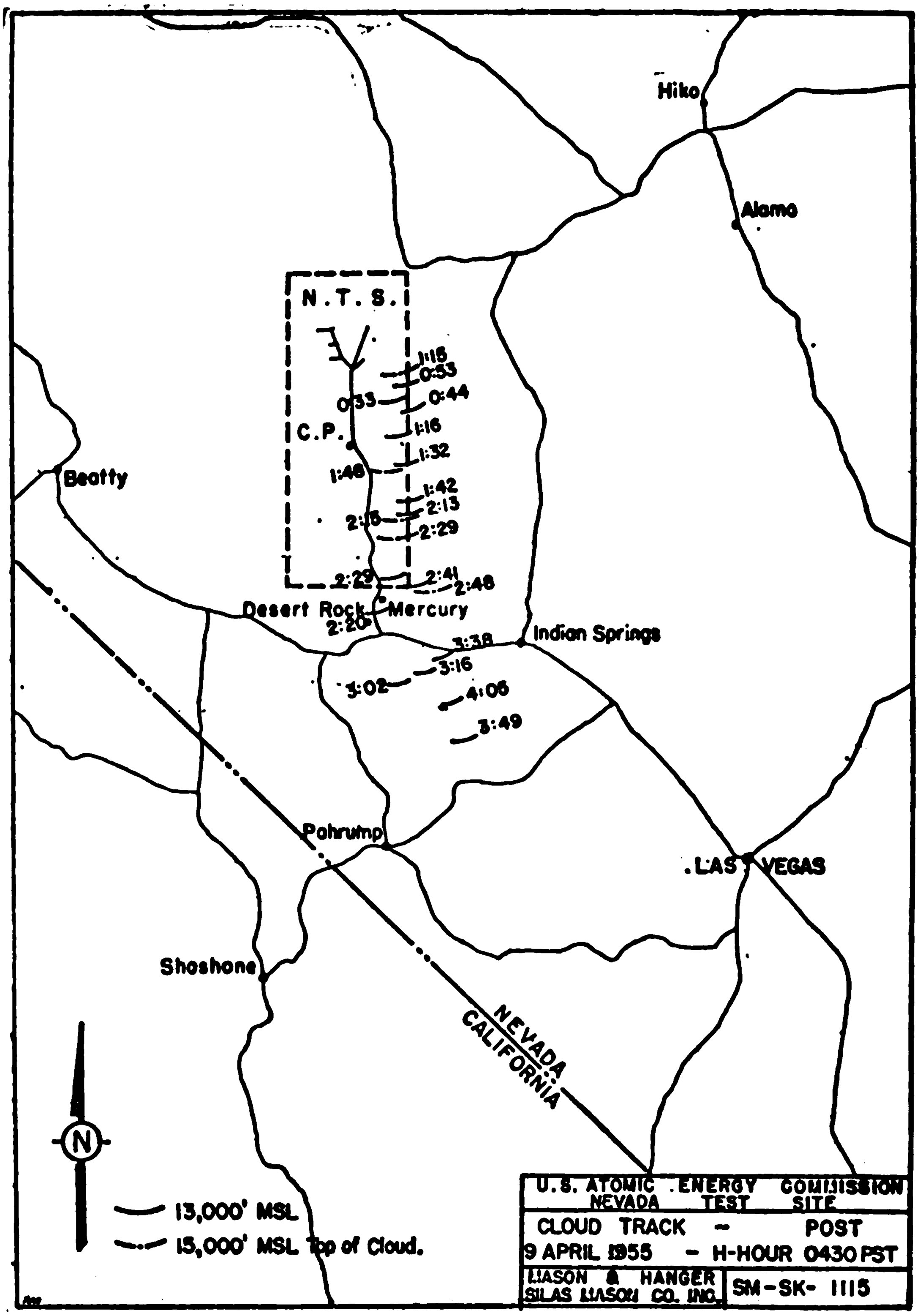
The maximum air radioactivity concentration measured was $9.0 \times 10^{-1} \mu c/m^3$, at Indian Springs, Nev. This represents the average air concentration for a 17.5-hour period starting at shot time.

Post: External gamma dose in populated areas and at selected nonpopulated points

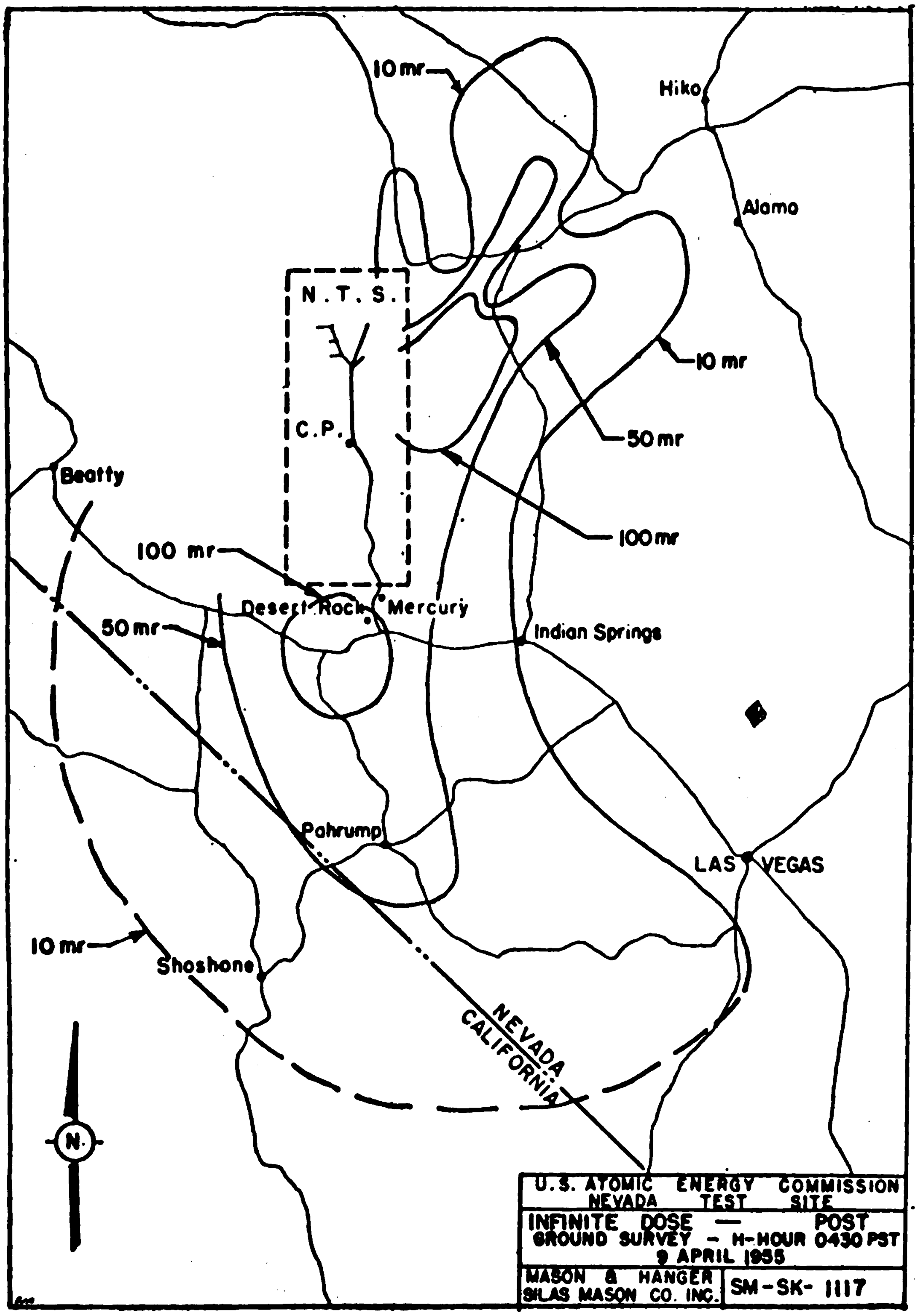
Location	Time of instrument reading (H+hours)	Gamma ground level (mr./hr.)	Time of fallout (H+hours)	Effective biological dose (mr.)	Infinite dose (mr.)
Populated areas:					
Pahrump, Nev	10.0	0.12	10.0	3	6
Quartz Mine (near Mercury, Nev.)	10.7	1.3	9.6	35	71
Cactus Springs, Nev	9.6	.14	9.6	3	7
Indian Springs, Nev	9.8	.3	9.8	7	15
Lathrop Wells, Nev	11.6	.7	10.0	21	42
Desert Rock, Nev	12.8	1.4	9.3	47	96
Mercury, Highway	13.0	1.2	9.3	42	84
Nonpopulated points:					
U. S. 95, 10 miles west of Mercury Highway	11.2	2.5	9.6	73	150
3.5 miles south of Papoose Lake	14.5	3.0	3.0	162	300



Hiko
Alamo
N.T.S.
C.P.
Beatty
4 R
Desert Rock
Mercury
Indian Springs
1 R
Pahrump
LAS VEGAS
Shoshone
NEVADA
CALIFORNIA
N
NOTE—
INFINITE DOSE PLOTTED.
U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
H Minus 1:30 FALLOUT PREDICTION
POST 9 APRIL 1955
H-HOUR 0430 PST
MASON & HANGER
SILAS MASON CO. INC.
SM-SK- 1116



Hiko
Alamo
N.T.S.
1:15
0:53
0:33
0:44
C.P.
1:16
1:32
1:48
Beatty
1:42
2:13
2:15
2:29
2:29
2:41
2:48
Desert Rock
Mercury
2:20
Indian Springs
3:38
3:16
3:02
4:05
3:49
Pahrump
LAS VEGAS
Shoshone
NEVADA
CALIFORNIA
N
13,000' MSL
15,000' MSL Top of Cloud.
U.S. ATOMIC ENERGY COMMISSION NEVADA TEST SITE
CLOUD TRACK - POST
9 APRIL 1955 - H-HOUR 0430 PST
MASON & HANGER SILAS MASON CO. INC.
SM-SK- 1115


10 mr
Hiko
Alamo
N. T. S.
C.P.
10 mr
50 mr
100 mr
Beatty
100 mr
Desert Rock
Mercury
50 mr
Indian Springs
Pahrump
LAS VEGAS
10 mr
Shoshone
NEVADA
CALIFORNIA
N.
U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
INFINITE DOSE — POST
GROUND SURVEY - H-HOUR 0430 PST
9 APRIL 1955
MASON & HANGER
SILAS MASON CO. INC.
SM-SK- 1117

Met

Met was a 400-foot tower detonation which was fired at 11:15 a. m. on April 15, 1955. The shot took place in Frenchman Flat.

The airway closure pattern was as follows:

1. A circular area around Yucca Flat, with a radius of 60 nautical miles, was ordered closed at all altitudes from 10:30 a. m. to 4 p. m.
2. A sector, with radii at 40° and 100°, length of radius 200 nautical miles, was ordered closed from 15,000 to 20,000 feet from 11 a. m. to 4 p. m.
3. A continuation of and including this sector, extending northeast to JL 2049 then southeast to the Arizona-New Mexico border at LG 4700, then west to KG 5000, then northwest along 100° radius to sector 2, above, was closed from 21,000 to 42,000 feet from 11 a. m. to 8 p. m.
4. An area from JL 2049 along the southern edge of airways Red 49 and Green 3 to Medicine Bow, then along the western edge of Green 3 to Denver, continuing along the western boundaries of Denver and the western edge of Amber 3 to Colorado Springs, and finally southwest to LG 5700 was ordered closed from 25,000 to 42,000 feet from 2:30 p. m. to 8 p. m.
5. At 12 noon, the top altitude in 3 and 4 above was changed from 42,000 feet to 44,000 feet, and the beginning closure time in 4 above was moved back to 2 p. m.
6. At 12:30 p. m. the bottom altitude in sector 2 above was lowered to 10,000 feet.
7. At 2:50 p. m., the flash circle was opened except that portion in sector 2 and the lower altitude in sectors 2 and 3 was raised to 21,000 feet effective at 3:15 p. m.
8. At 4 p. m., area 4 was reduced by opening the area south of airway Victor B effective at 4:15 p. m.

The cloud was tracked by one B-25, two B-50's, and sampler aircraft. Maximum cloud height observed was 42,800 feet, settling quickly to 41,300 feet. Base of the mushroom was reported at 28,000 feet. The cloud was tracked to a maximum distance of 200 nautical miles on an approximate true bearing of 65° from the C. P. In general, all levels (13,000, 23,000, 28,000, and 42,000 feet) tracked followed the same bearing.

A low-level terrain survey was made by one C-47 aircraft from approximately H plus 3 hours and 15 minutes to H plus 7 hours. The fallout pattern is plotted on the accompanying map. Due to the relatively late detonation time, the aerial survey had to be cut short, as the aircraft could not conduct the low-level survey after sunset. For this reason, sufficient data to close the 1 r. infinite dose contour was not obtained.

Monitoring runs, which indicated activity substantially above background, were made along U. S. 93 between 36 miles north of Glendale, Nev., and the junction of Nevada 25; on Utah 21 between Beaver, Utah, and 7 miles west of Milford, Utah; on U. S. 91 between 5 miles north of Cove Fort, Utah, and Parowan, Utah; along Nevada 25 and Utah 56 between U. S. 93 and Newcastle, Utah; along Nevada 55 between 4 miles south of Elgin, Nev., to Caliente, Nev.; on Utah 18 between Enterprise, Utah, and Beryl Junction, Utah; along Utah 98 from Beryl Junction, Utah, to Beryl, Utah; on Utah 19 between Lund, Utah, and the junction of Utah 56; on the desert road north of Indian Springs, Nev.; along the game preserve road north of U. S. 95; and on several other desert roads northeast of the Nevada test site.

The maximum effective biological dose for a populated area was 2,880 mr. at Elgin, Nev. The maximum effective biological dose at a nonpopulated point was 44,600 mr. 24 miles north of Indian Springs, Nev.

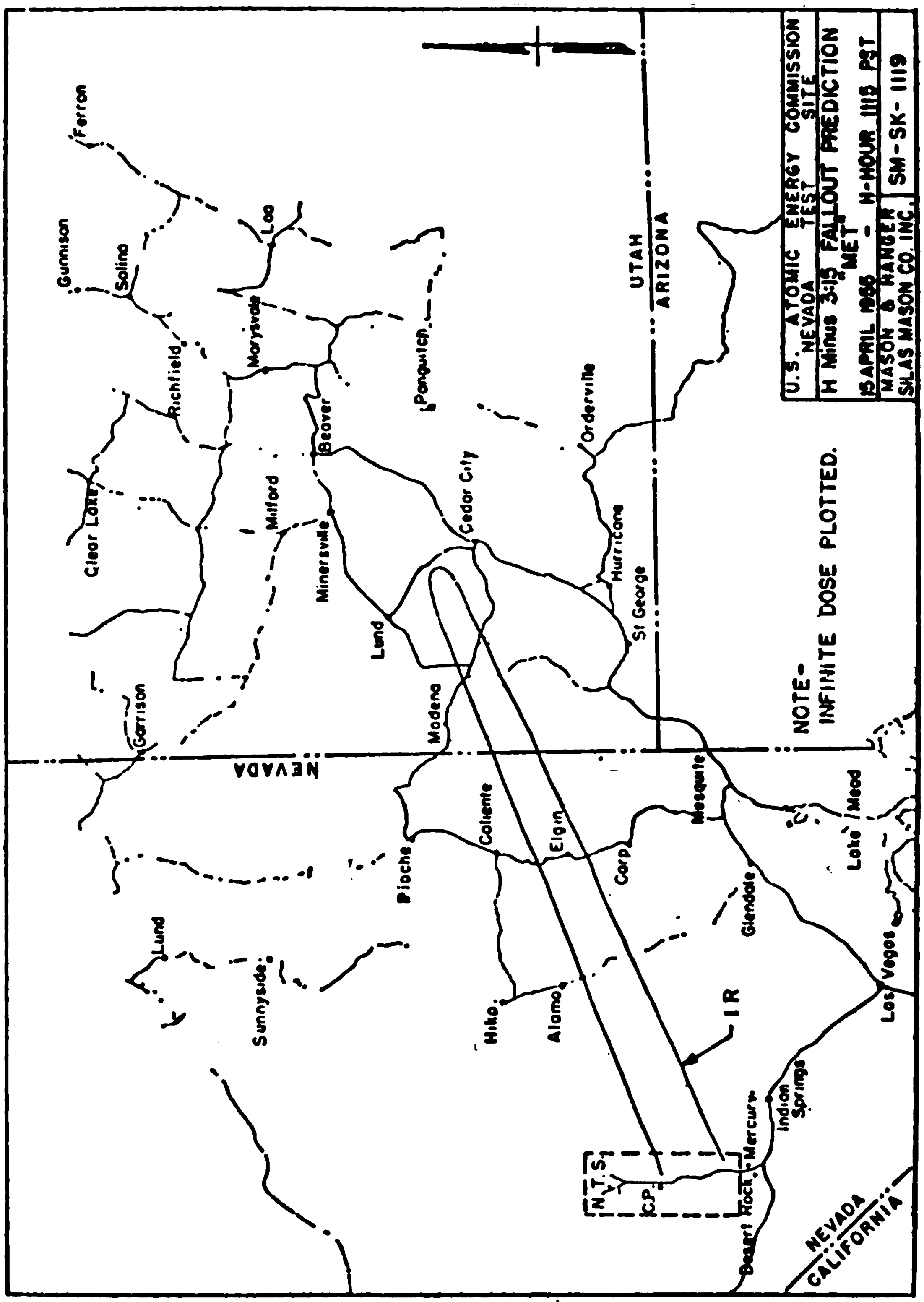
Approximately 340 individual monitoring readings above 0.1 mr./hr. were recorded.

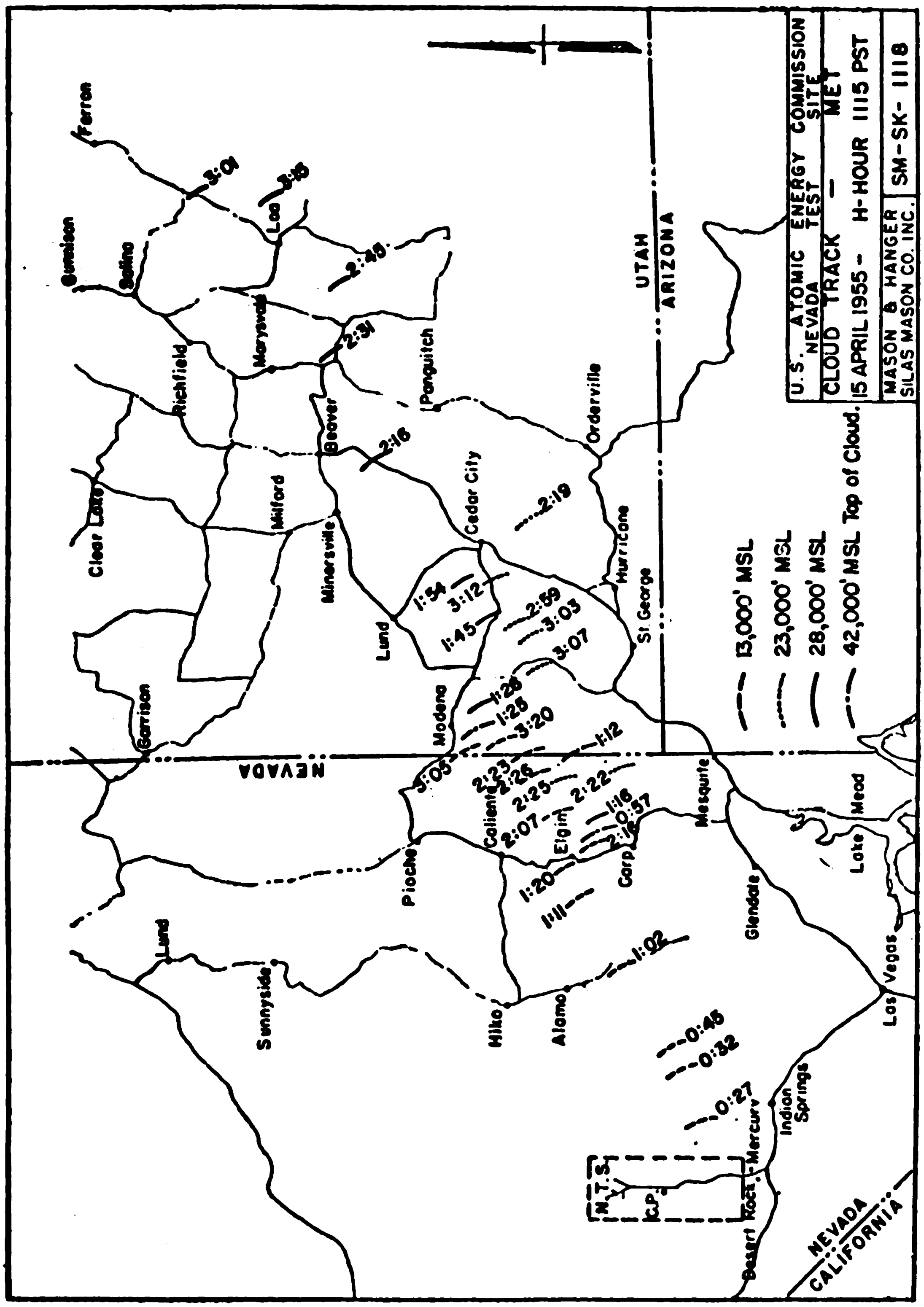
In general, all the maps are in good agreement as to both direction and magnitude. The actual 1 r. infinite isodose contour was a few miles longer than predicted, terminating northeast of Utah 21 rather than southwest. It is apparent that the 10 r. infinite isodose line crossed U. S. 93 southeast of Alamo, Nev.

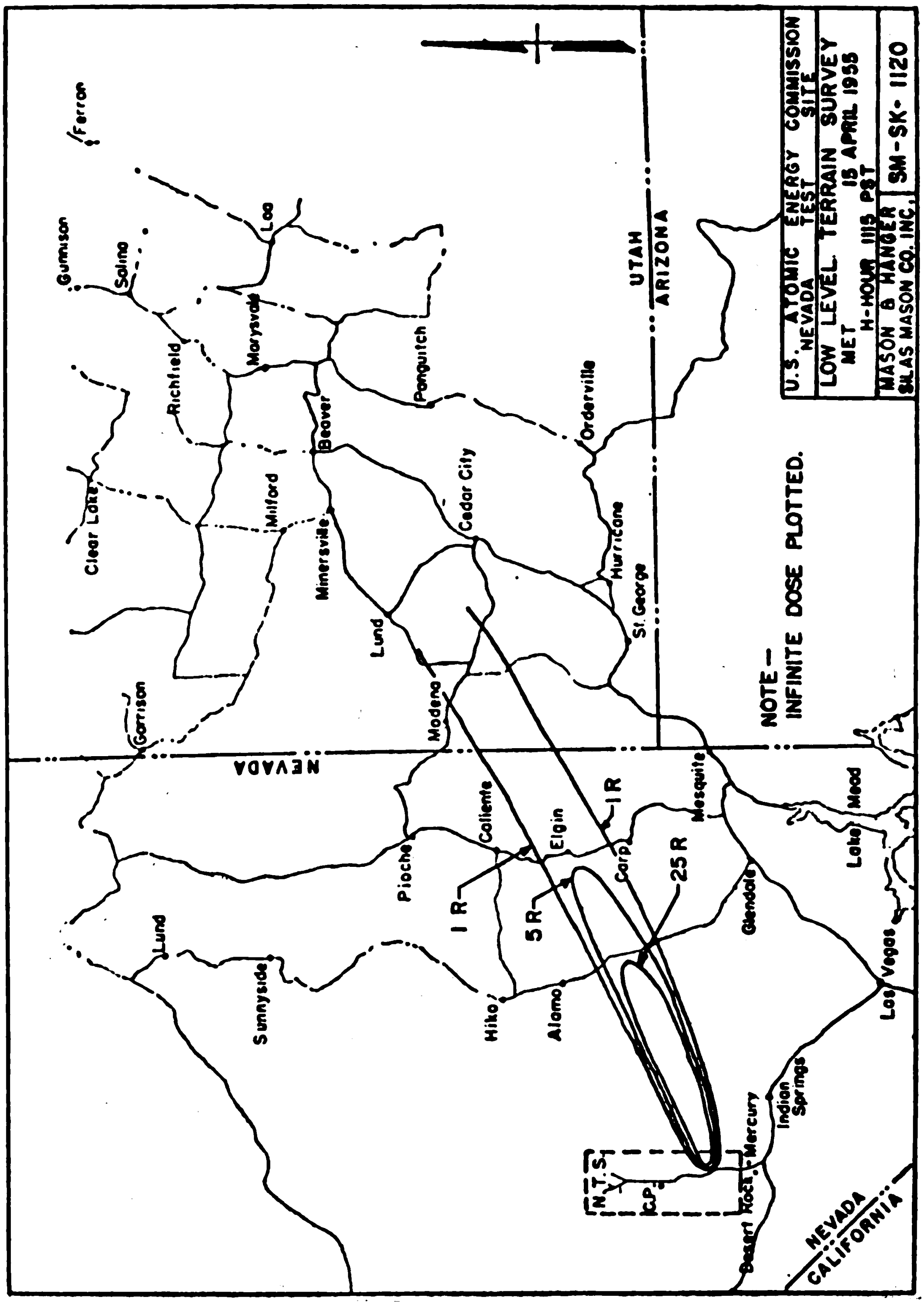
The maximum air radioactivity concentration measured was $6.1 \times 10^{-2} \mu c/m^3$, at Beaver, Utah. This represents the average air concentration for a 24.8-hour period starting at shot time.

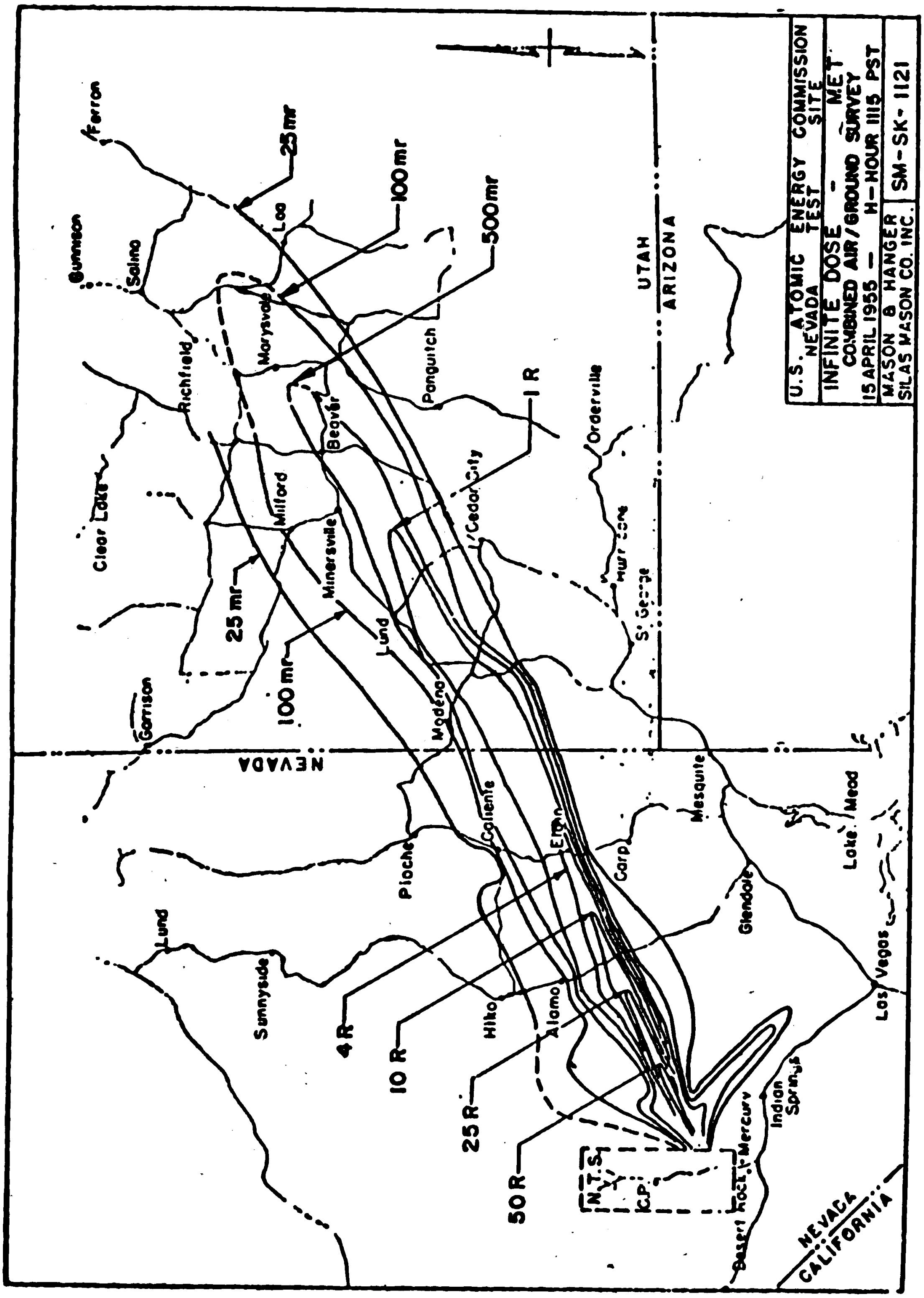
Met: External gamma dose in populated areas and at selected nonpopulated points

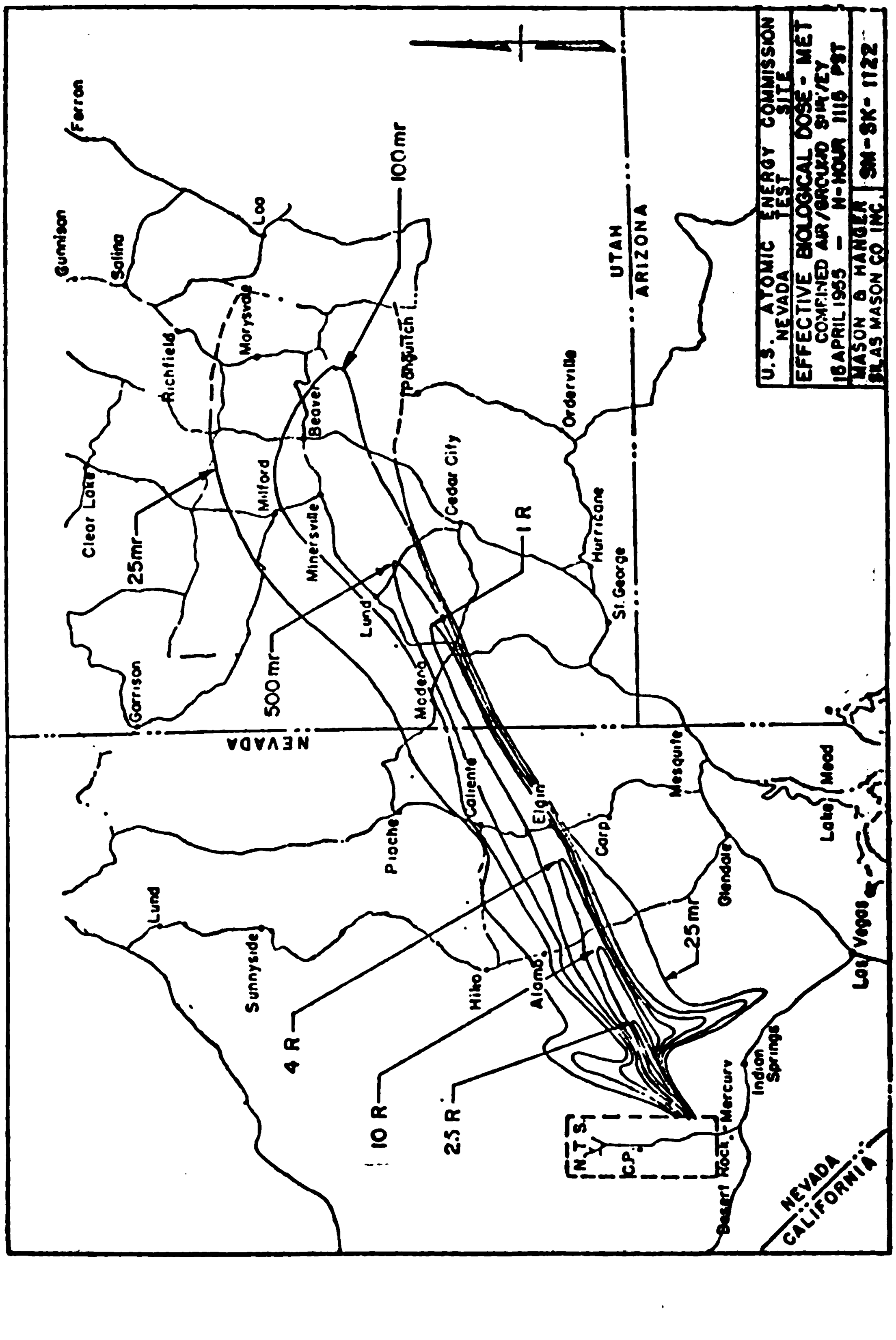
Location	Time of instrument reading (H+hours)	Gamma ground level (mr./hr.)	Time of fallout (H+hours)	Effective biological dose (mr.)	Infinite dose (mr.)
Populated areas:					
Alamo, Nev	3.6	4.2	2.6	45	82
Buckhorn Ranch, Nev	2.6	140.0	2.6	980	1,750
Caliente, Nev	6.1	8.0	4.3	140	260
Elgin, Nev	5.1	200.0	3.9	2,880	5,340
Panaca, Nev	6.5	5.0	4.9	91	170
Modena, Utah	6.6	3.5	5.9	62	120
Enterprise, Utah	6.0	.13	6.0	2	4
Beryl Junction, Utah	28.8	3.6	6.2	370	700
Beryl, Utah	6.6	6.0	6.6	102	200
Zane, Utah	6.8	16.0	6.8	275	525
Lund, Utah	7.3	9.0	7.3	170	330
Cedar City, Utah	7.8	.3	7.6	6	12
Paragonah, Utah	25.9	.2	8.5	16	32
Parowan, Utah	26.0	.1	8.3	5	10
Beaver, Utah	25.3	3.5	9.3	270	540
Minersville, Utah	22.1	2.5	8.6	170	330
Milford, Utah	22.7	1.0	8.7	70	140
Cove Fort, Utah	24.3	.4	9.9	29	58
Newcastle, Utah	29.3	.1	6.5	7	14
Nonpopulated points:					
U. S. 93, 16 miles south of Alamo, Nev	2.9	950.0	2.6	7,630	13,800
24 miles north of Indian Springs, Nev	24.6	270.0	.9	44,600	74,300


U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
H Minus 3:15 FALLOUT PREDICTION
"MET"
15 APRIL 1956 - H-HOUR 1115 PST
MASON & HANGER
SILAS MASON CO. INC.
SM-SK-1119
NOTE-
INFINITE DOSE PLOTTED.
UTAH
ARIZONA
NEVADA
NEVADA
CALIFORNIA
Ferron
Gunnison
Salina
Loa
Richfield
Marysvale
Panguitch
Beaver
Orderville
Clear Lake
Milford
Minersville
Cedar City
Hurricane
St George
Lund
Modena
Garrison
Caliente
Elgin
Mesquite
Lake Mead
Carp
Pioche
Glendale
Lund
Sunnyside
Hiko
Alamo
IR
Las Vegas
Indian Springs
Mercury
N.T.S.
C.P.
Desert Rock


U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
CLOUD TRACK - MET
15 APRIL 1955 - H-HOUR 1115 PST
MASON & HANGER
SILAS MASON CO. INC.
SM-SK-1118
13,000' MSL
23,000' MSL
28,000' MSL
42,000' MSL Top of Cloud.
UTAH
ARIZONA
NEVADA
NEVADA
CALIFORNIA
Ferron
Gunnison
Salina
Loa
Marysvale
Richfield
Panguitch
Beaver
Orderville
Clear Lake
Milford
Cedar City
Minersville
Hurricane
St. George
Lund
Garrison
Modena
Caliente
Elgin
Carp
Mesquite
Lake Mead
Pioche
Glendale
Lund
Sunnyside
Hiko
Alamo
Las Vegas
Indian Springs
Mercury
N.T.S.
C.P.
Desert Rock


U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
LOW LEVEL TERRAIN SURVEY
MET 15 APRIL 1955
H-HOUR 1115 PST
MASON & HANGER
SILAS MASON CO. INC.
SM-SK-1120
NOTE—
INFINITE DOSE PLOTTED.
UTAH
ARIZONA
NEVADA
NEVADA
CALIFORNIA
Ferron
Gunnison
Salina
Loa
Richfield
Marysvale
Panguitch
Orderville
Beaver
Milford
Clear Lake
Minersville
Cedar City
Hurricane
St. George
Lund
Modena
Garrison
Mesquite
Caliente
Elgin
Carp
Pioche
1 R
5 R
25 R
1 R
Lund
Sunnyside
Hiko
Alamo
Glendale
Lake Mead
Las Vegas
Indian Springs
Mercury
Desert Rock
N.T.S.
C.P.


U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
INFINITE DOSE - MET
COMBINED AIR/GROUND SURVEY
15 APRIL 1955 — H-HOUR 1115 PST
MASON & HANGER
SILAS MASON CO. INC.
SM-SK-1121
UTAH
ARIZONA
NEVADA
NEVADA
CALIFORNIA
25 mr
100 mr
500 mr
1 R
4 R
10 R
25 R
50 R
Ferron
Gunnison
Salina
Loa
Richfield
Marysvale
Panguitch
Beaver
Orderville
Clear Lake
Milford
Minersville
Cedar City
Lund
Modena
Garrison
Caliente
Pioche
Enterprise
Carp
Mesquite
Lake Mead
Glendale
Lund
Sunnyside
Hiko
Alamo
Las Vegas
Indian Springs
Mercury
N.T.S.
C.P.


U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
EFFECTIVE BIOLOGICAL DOSE - MET
18 APRIL 1955 — H-HOUR 1115 PST
MASON & HANGER
SILAS MASON CO INC.
SM-SK-1122
UTAH
ARIZONA
NEVADA
NEVADA
CALIFORNIA
Ferron
Gunnison
Salina
Loa
Marysvale
Richfield
Panguitch
Beaver
Milford
Clear Lake
Cedar City
Minersville
Lund
Modena
Garrison
Orderville
Hurricane
St. George
Mesquite
Lake Mead
Caliente
Elgin
Carp
Pioche
Glendale
Las Vegas
Indian Springs
Mercury
Desert Rock
N.T.S.
C.P.
Alamo
Hiko
Sunnyside
Lund
25mr
100mr
500mr
1 R
4 R
10 R
25 R
25mr

APPLE TWO

Apple Two was a 500-foot tower detonation which was fired at 5:10 a. m. on May 5, 1955. The shot took place in test area 1 in Yucca Flat.

The airway closure pattern was as follows:

1. A circular area around Yucca Flat, with a radius of 60 nautical miles, was ordered closed at all altitudes from 4:45 a. m. to 9:30 a. m. The southern half of this circle was to be opened at H plus 10 miutes.
2. A sector, radii at 315° and 20°, length of radius 140 nautical miles, was closed from 14,000 to 24,000 feet from 6:30 a. m. to 9 a. m.
3. A sector, radii at 335° and 30°, length of radius 200 nautical miles, was closed from 24,000 to 44,000 feet from 6 a. m. to 10 a. m.
4. A continuation of this sector 3, above, extending the radius to 400 nautical miles, was closed from 24,000 to 44,000 feet from 8:30 a. m. to 12 noon.
5. At 6:30 a. m. the 30° bearing in sectors 3, and 4, was changed to 50°, and the extreme length of radius was reduced to 300 nautical miles.
6. At 8 a. m. the end closure time in 3. was changed to 12 noon, and the start closure time in 4. was changed to 9 a. m.
7. At 10:10 a. m., sector 4. was opened at all altitudes.

Cloud track data were received from one B-25, two B-50's, and sampler aircraft. Maximum cloud height observed was 40,500 feet. Considerable shear was present and the various levels tracked showed a spread in bearing from about 340° to 60°. The cloud was tracked to a miximum distance of about 120 nautical miles at all levels. The plot of the several tracks is shown on the accompanying map.

A preshot survey was flown on D-3 days since the zone of predicted fallout was in a direction not extensively surveyed by air previously. A low level terrain survey was flown by one C-47 aircraft from H plus 5 hours to approximately H plus 10 hours and 30 minutes. Results of this survey are plotted on the accompanying map.

Monitoring runs, which indicated activity substantially above background, were made along U. S. 93 between 45 miles north of Pioche, Nev., and Ely, Nev.; on Nevada 25 between U. S. 6 and several miles west of Lincoln Mine, Nev.; on U. S. 6 between 1 mile east of Warm Springs, Nev., and Ely, Nev.; along Nevada 20 between Currant, Nev. and U. S. 50; on U. S. 50 between 55 miles west of Eureka, Nev., and Nevada 73; along Nevada 73 between U. S. 50 and Nevada 21; on Utah 21 between Nevada 73 and 25 miles east of Garrison, Utah; along Nevada 38 between Sunnyside, Nev., and 3 miles south of Sunnyside, Nev.; and along several of the desert roads north of the Nevada test site.

The maximum effective biological dose for a populated area was 2,580 mr. at Reed, Nev. The maximum effective biological dose at a nonpopulated point was 6,270 mr. in Kawich Valley northwest of the Nevada test site.

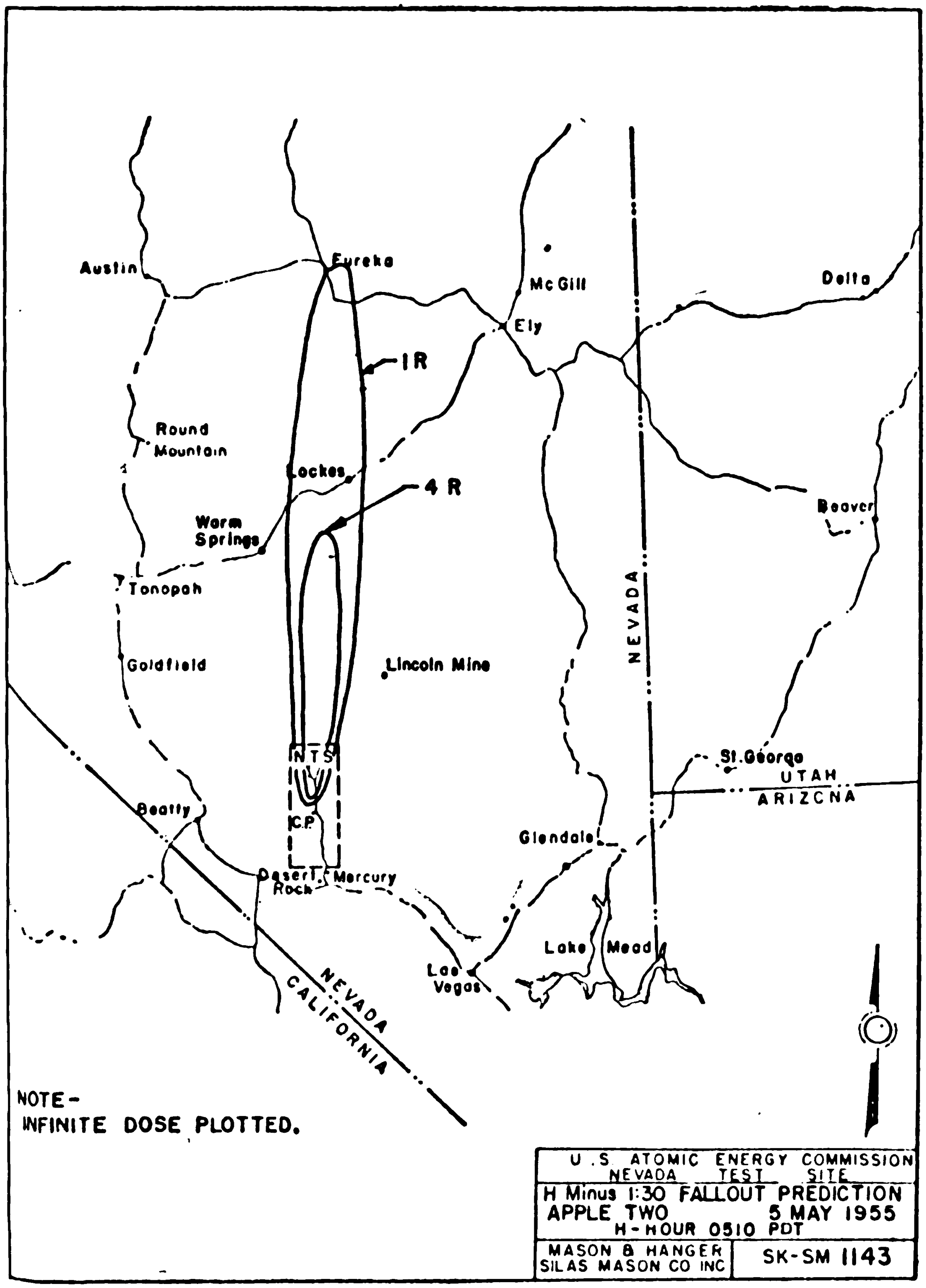
Approximately 385 individual monitoring readings above 0.1 mr/hr., were recorded.

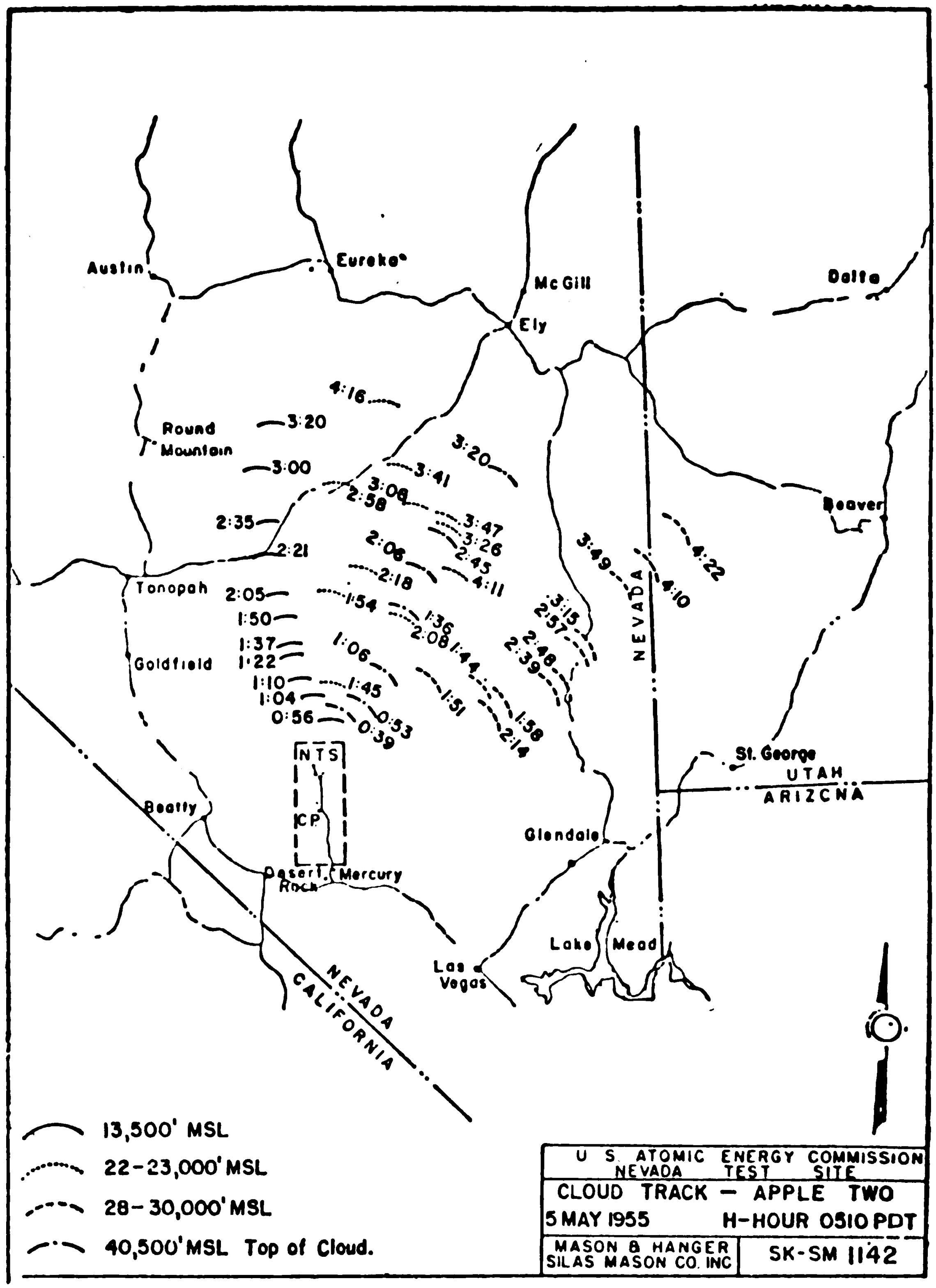
A comparison of the prediction map and the factual maps indicates good directional agreement with an overprediction in magnitude (length of isodose contours). The cloud track map shows one reason for the overprediction, and that is shear. The cloud was dispersed to a great extent laterally. The ground survey infinite dose map shows the 1 r. contour crossing U. S. 6 about midway between Tonopah and Ely, Nev. The shear, previously mentioned, is also evident in the construction of the isodose lines.

The maximum air radioactivity concentration measured was 5.9×10^{-3} $\mu c/m^3$, at Ely, Nev. This represents the average air concentration for a 28-hour period starting at shot time.

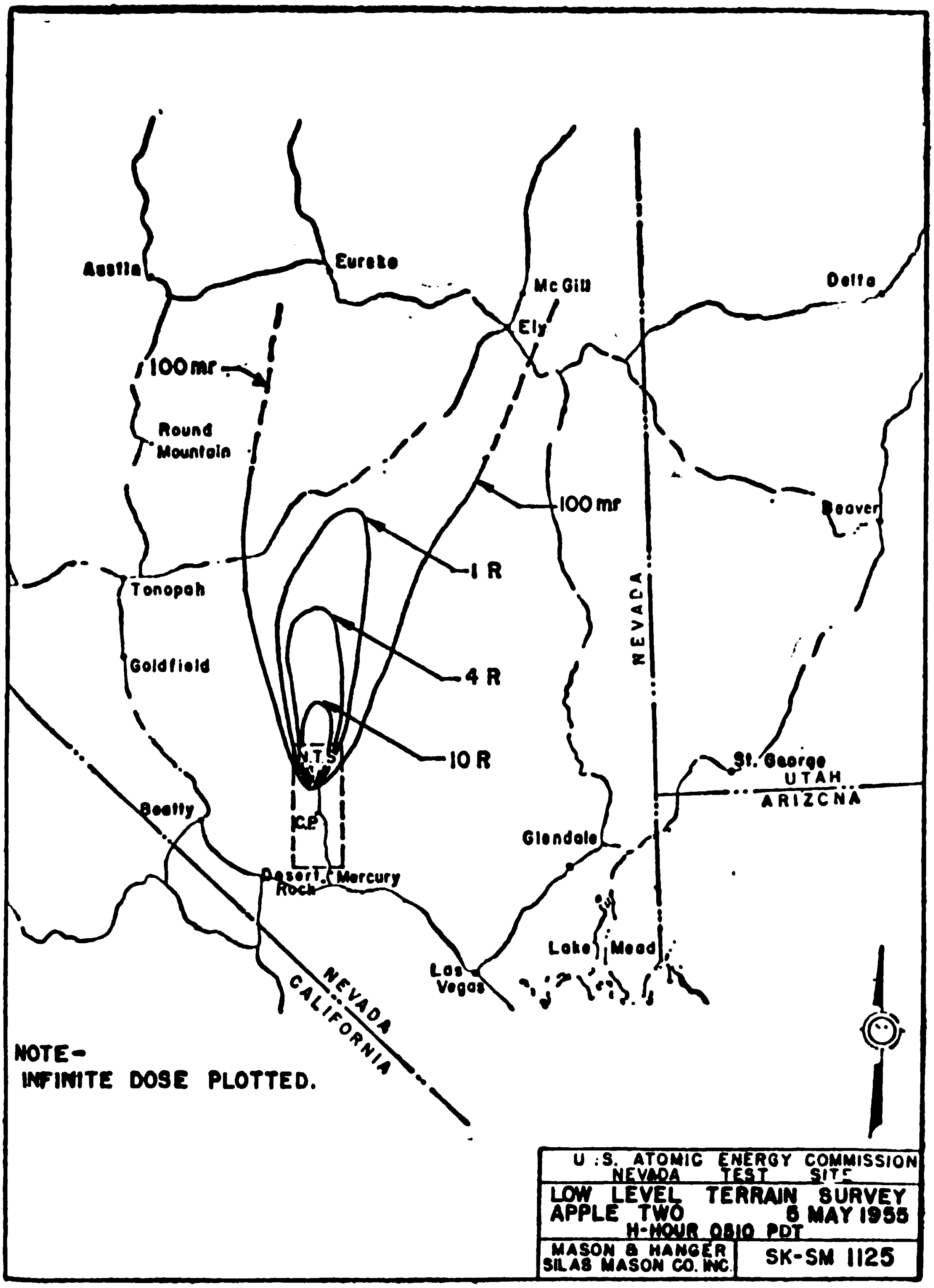
Apple Two: External gamma dose in populated areas and at selected nonpopulated points

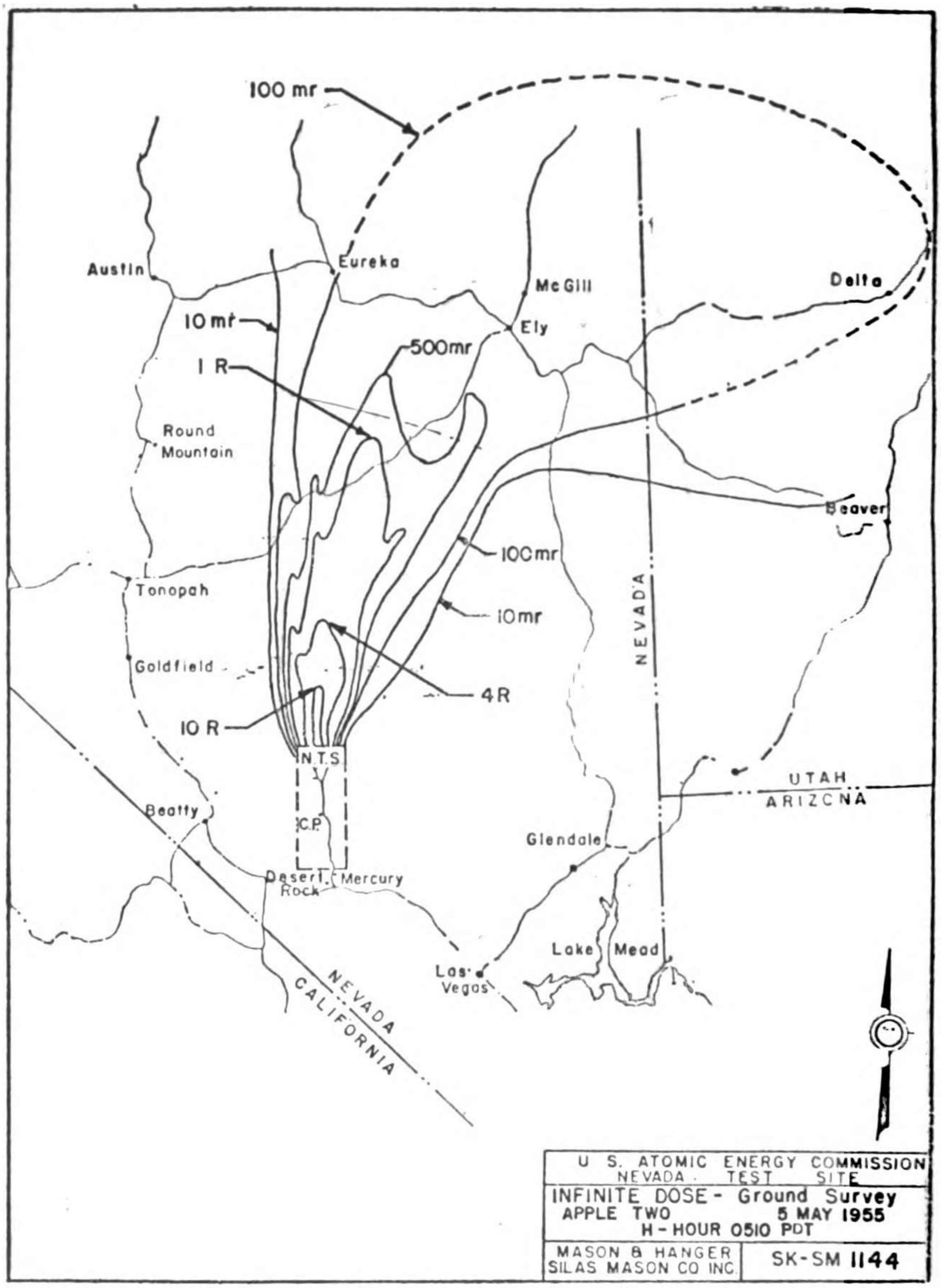
Location	Time of instrument reading (H+hours)	Gamma ground level (mr./hr.)	Time of fallout (H+hours)	Effective biological dose (mr.)	Infinite dose (mr.)
Populated areas:					
Adaven, Nev	4.2	18.0	4.1	200	370
Nyala, Nev	5.8	30.0	4.4	500	930
Lincoln Mine, Nev	15.0	.3	2.6	18	32
Fallini Ranch, Nev	5.0	13.0	4.2	250	460
Reed, Nev	6.8	110.0	2.5	2,580	4,59[illegible]
Sunnyside, Nev	5.6	.4	5.6	5	10
Warm Springs, Nev	7.5	.3	4.2	6	11
Lockes Ranch, Nev	5.8	38.0	5.3	530	1,010
Currant, Nev	6.5	8.0	6.4	130	2[illegible]0
Duckwater, Nev	7.3	16.0	6.8	300	5[illegible]0
Lund, Nev	11.9	7.5	7.3	250	490
Ely, Nev	13.7	6.5	8.7	250	4[illegible]0
Baker, Nev	36.1	.8	9.1	95	190
Garrison, Utah	36.3	.5	9.0	60	120
Eureka, Nev	9.1	.8	9.1	18	36
Nonpopulated points:					
U. S. 6, 4 miles west of Lockes Ranch, Nev	5.4	55.0	5.3	790	1,490
Kawich Valley, Nev	4.2	440.0	1.8	6,270	10,900

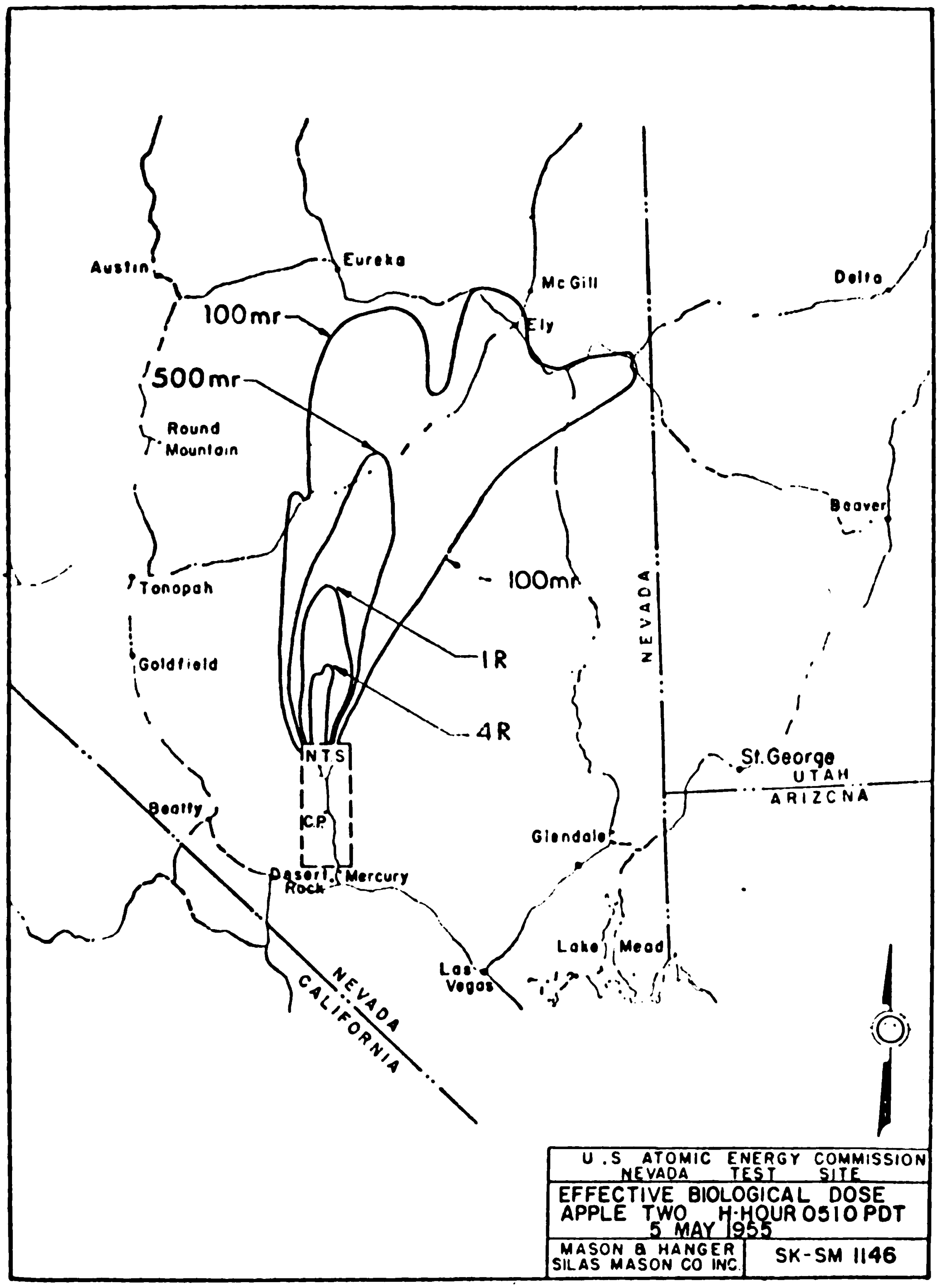

Austin
Eureka
McGill
Ely
Delta
1R
Round Mountain
Lockes
4 R
Warm Springs
Tonopah
Beaver
NEVADA
Goldfield
Lincoln Mine
NTS
St. George
UTAH
ARIZONA
Beatty
C.P.
Glendale
Desert Rock
Mercury
Lake Mead
Las Vegas
NEVADA
CALIFORNIA
NOTE-
INFINITE DOSE PLOTTED.
U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
H Minus 1:30 FALLOUT PREDICTION
APPLE TWO 5 MAY 1955
H-HOUR 0510 PDT
MASON & HANGER
SILAS MASON CO INC
SK-SM 1143



Austin
Eureka
McGill
Ely
Delta
Round Mountain
Beaver
Tonopah
Goldfield
NEVADA
St. George
UTAH
ARIZONA
Beatty
NTS
CP
Desert Rock
Mercury
Glendale
Lake Mead
Las Vegas
NEVADA
CALIFORNIA
4:16
3:20
3:00
2:35
2:21
2:05
1:50
1:37
1:22
1:10
1:04
0:56
3:20
3:41
3:08
2:58
3:47
3:26
2:45
2:06
2:18
4:11
1:54
1:36
2:08
1:44
1:06
1:45
0:53
0:39
1:51
1:58
2:14
3:49
4:10
4:22
3:15
2:57
2:48
2:39
13,500' MSL
22-23,000' MSL
28-30,000' MSL
40,500' MSL Top of Cloud.
U. S. ATOMIC ENERGY COMMISSION NEVADA TEST SITE
CLOUD TRACK — APPLE TWO
5 MAY 1955
H-HOUR 0510 PDT
MASON & HANGER SILAS MASON CO. INC
SK-SM 1142


Austin
Eureka
McGill
Ely
Delta
100 mr
Round Mountain
100 mr
Beaver
Tonopah
1 R
Goldfield
4 R
NEVADA
10 R
N.T.S.
St. George
UTAH
ARIZONA
Beatty
C.P.
Glendale
Desert Rock
Mercury
Lake Mead
Las Vegas
NEVADA
CALIFORNIA
NOTE-
INFINITE DOSE PLOTTED.
U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
LOW LEVEL TERRAIN SURVEY
APPLE TWO 5 MAY 1955
H-HOUR 0510 PDT
MASON & HANGER
SILAS MASON CO. INC.
SK-SM 1125


100 mr
Austin
Eureka
McGill
Ely
Delta
10 mr
1 R
500mr
Round Mountain
Beaver
100mr
Tonopah
10mr
NEVADA
Goldfield
4R
10 R
N.T.S.
UTAH
ARIZONA
Beatty
C.P.
Glendale
Desert Rock
Mercury
Lake Mead
Las Vegas
NEVADA
CALIFORNIA
U. S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
INFINITE DOSE - Ground Survey
APPLE TWO 5 MAY 1955
H-HOUR 0510 PDT
MASON & HANGER
SILAS MASON CO INC.
SK-SM 1144


Austin
Eureka
McGill
Ely
Delta
100mr
500mr
Round Mountain
Beaver
Tonopah
100mr
Goldfield
1R
4R
NEVADA
NTS
St. George
UTAH
ARIZONA
Beatty
C.P.
Glendale
Desert Rock
Mercury
Lake Mead
Las Vegas
NEVADA
CALIFORNIA
U.S ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
EFFECTIVE BIOLOGICAL DOSE
APPLE TWO H-HOUR 0510 PDT
5 MAY 1955
MASON & HANGER
SILAS MASON CO INC.
SK-SM 1146

Zucchini

Zucchini was a 500-foot tower detonation which was fired at 5 a. m. on May 15, 1955. The shot took place in test area 7 in Yucca Flat.

The airway closure pattern was as follows:

1. Starting the evening of May 14 at 10:11 p. m., the warning circle was set up as a 265-nautical-mile radius at the Grand Canyon Airport. The flash circle was a standard 60-nautical-mile radius of the coordinates 37° N. 116° W. and closed at all altitudes from 4:30 to 9:30 a. m. The low-level closure was between the bearings of 140° and 180° for a distance of 120 nautical miles and closed at the altitudes from the surface through 13,000 feet. The time of closure was 6:30 a. m. to 9 a. m. The middle-level closure was between bearing lines of 100° and 180°, determined by extending the 180° line for 150 nautical miles and extending the 100° line for 340 nautical miles with an arc of 340-nautical-mile radius drawn off the 100° bearing; then at a distance of 150 nautical miles on the 180° line, a direct line extending through the Phoenix low-frequency radio range station to intersect the 340-nautical-mile arc. The first segment of the middle level was the area extending from the test site out 150 nautical miles. This area was closed at 13,000 feet through 23,000 feet, inclusive. The time of closure was 5:45 a. m. to 10 a. m. The second segment was all the area between 150 nautical miles and 340 nautical miles and closed at the altitudes of 16,000 to 23,000 feet, inclusive, from 7:15 a. m. to 10 a. m. The high-level closure was between the bearings of 50° and 140°. The 140° line was extended to intersect the north edge of airway Green 4, then direct to the 4 corners, direct to the Grand Junction low-frequency-range station. The 50° line was extended across the east course of the Delta, Utah, radio-range station and direct to Grand Junction. The first segment of the high-level closure was all the area west of a line drawn from Delta to the Grand Canyon Airport. The altitudes closed were 23,000 to 40,000 feet from 5:30 to 8:45 a. m. The second segment was all the area east of the Delta-Grand Canyon line and closed at the altitudes of 23,000 to 40,000 feet from 6:45 a. m. to 12 noon.
2. At 6:07 a. m., tracking aircraft reports indicated the low-level trajectories had changed, and the 140° and 180° bearing lines were changed to read 100° and 140°. The closure time remained the same.
3. At 6:26 a. m., the middle-level closure was changed to correspond with the high-level closure. This area was then closed at the altitudes of 13,000 to 40,000 feet, inclusive.
4. At 7:05 a. m., the combined high- and middle-level areas were extended from Delta, Utah, directly to the south edge of airway Green 3 at Fort Bridger, Wyo., then east along the south edge of airway Green 3 to Medicine Bow, then south along the west edge of Green 10 to Denver, then west to the north edge of airway Victor 8 to Grand Junction.
5. At 8:26 a. m., closures remaining effective at 9 a. m. were the second segment of the high- and middle-level closure lying east of the Delta-Grand Canyon line. This area was then closed at altitudes 20,000 to 40,000 feet, inclusive, from 9 a. m. to 12 noon. All tracking aircraft were returned to base and no further changes were made.

The cloud was tracked by 1 B–25 at 13,000 feet, 2 B–50's at 23,000 and 28,000 feet, respectively, and by sampler aircraft at approximately 35,000 feet. Maximum cloud height reported was 37,700 feet, stabilizing at 36,300 feet. The cloud was tracked by the B–50's and sampler aircraft on an approximate bearing of 69° for a distance of 218 nautical miles. The low-level portion was followed 145 nautical miles on a 118° bearing.

A low-level terrain survey was made by 1 C–47 aircraft from H plus 5 hours and 30 minutes to H plus 10 hours and 30 minutes. The accompanying map shows that fallout occurred along an approximate bearing of 105°.

Monitoring runs, which indicated activity substantially above background, were made along Utah 18 from 3 to 38 miles south of Enterprise, Utah; on U. S. 91–93 from Glendale, Nev., to 4 miles south of Apex, Nev.; along U. S. 91 from Glendale, Nev., to Paragonah, Utah; along U. S. 93 from Glendale, Nev., to 38 miles north of Glendale; on Warm Springs Ranch, Nev., Road; along the Mormon Mesa Road; on the roads in the Moapa Indian Reservation; on Nevada 40; on Nevada 12; and along several of the roads east of the Nevada test site.

The maximum effective biological dose for a populated area was 700 mr. at Moapa, Nev. The maximum effective biological dose at a nonpopulated point was 19,900 mr., 7.5 miles south of Papoose Lake.

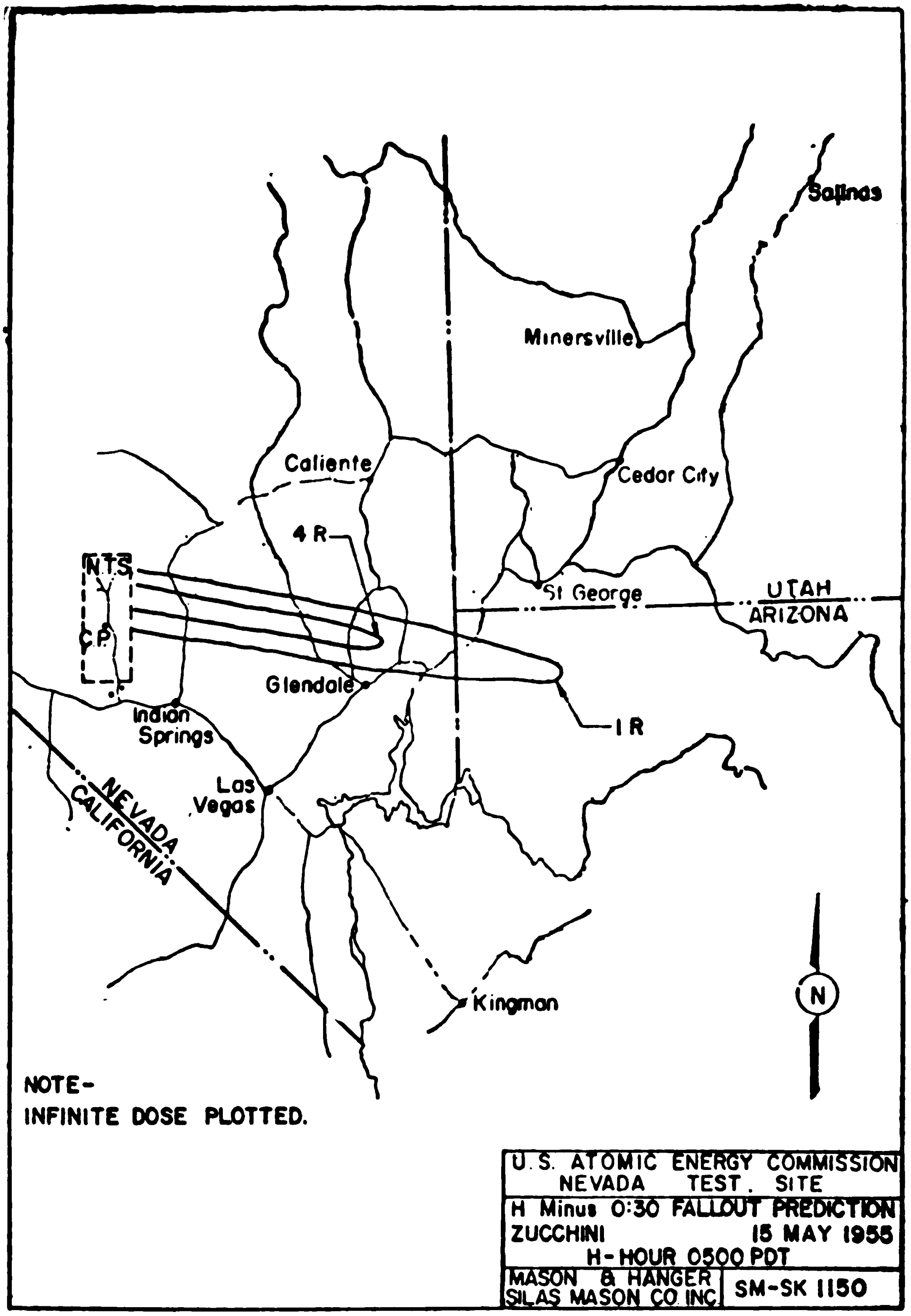
Approximately 375 individual monitoring readings above 0.1 mr./hr. were recorded.

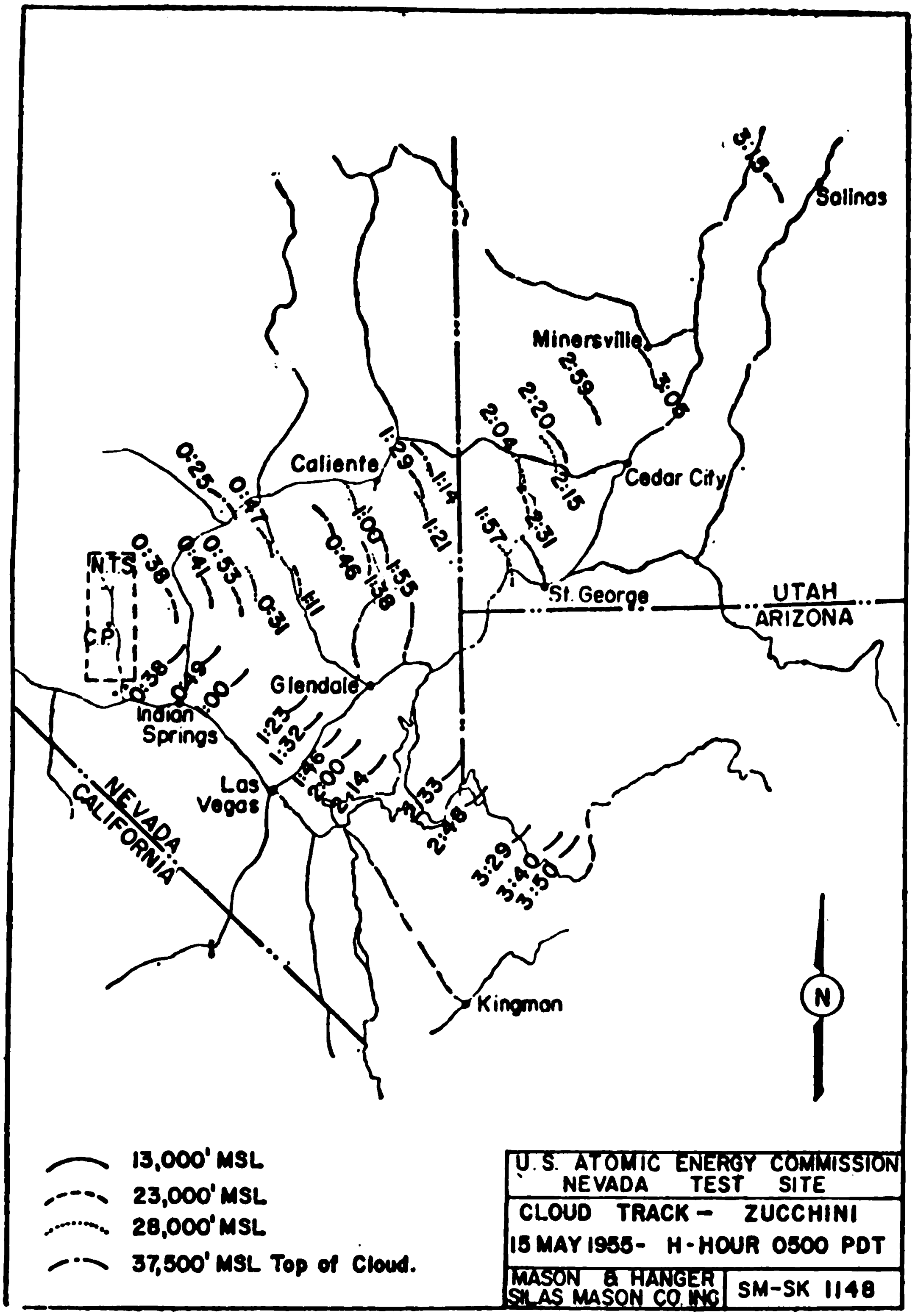
A comparison of the prediction map and the factual maps indicates an over-prediction in magnitude and a 5° to 10° difference in direction. The low-level terrain survey map shows good agreement with ground survey results with the exception that it indicates shorter isodose lines. The ground survey map shows an additional light fallout pattern to the northeast. One r. infinite isodose contour intersected U. S. 91 and U. S. 93 in the vicinity of Glendale, Nev.

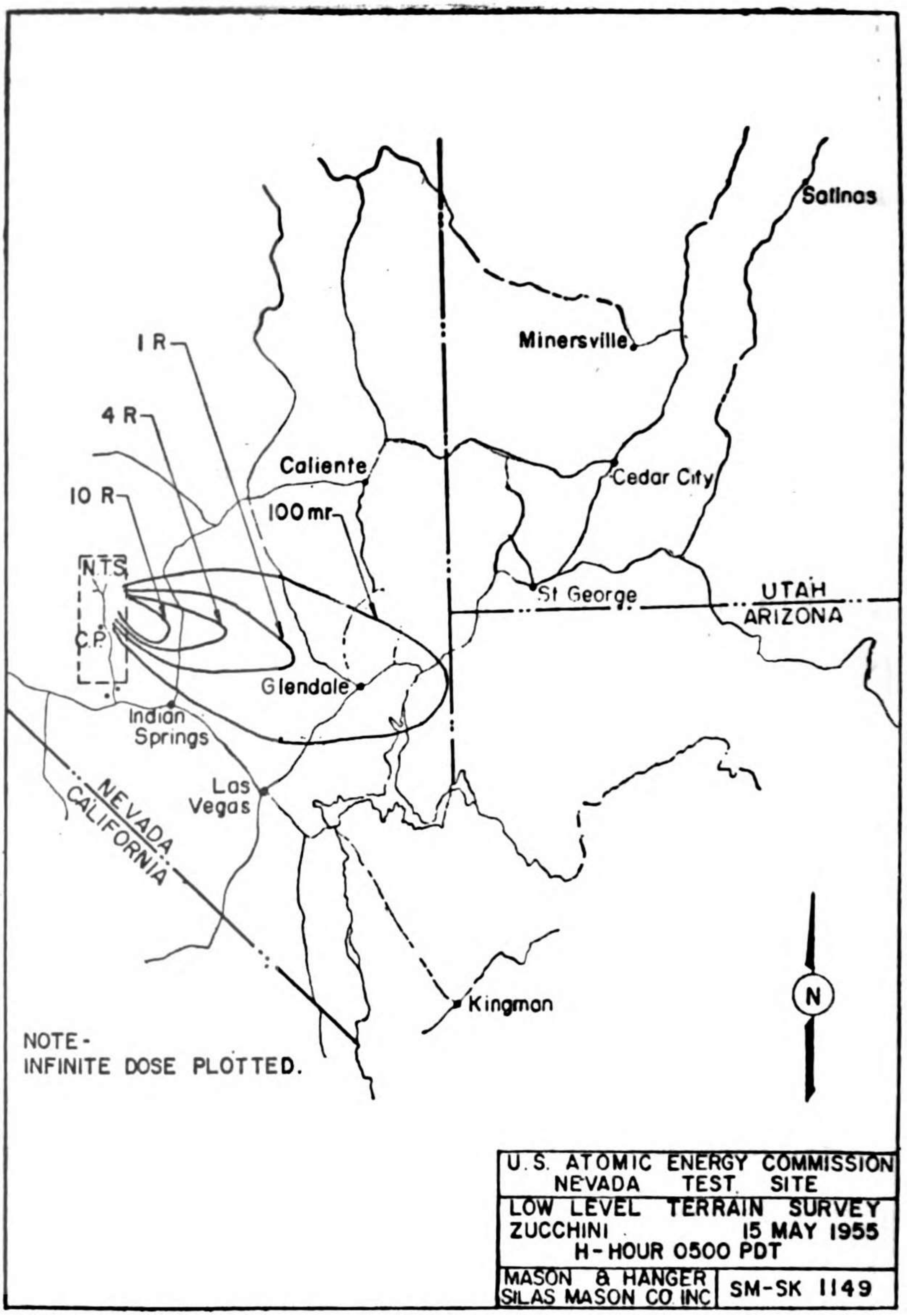
The maximum air radioactivity concentration measured was 7.8×10^{-4} $\mu c/m^3$, at Cedar City, Utah. This represents the average air concentration for a 28.2-hour period starting at shot time.

Zucchini: External gamma dose in populated areas and at selected nonpopulated points

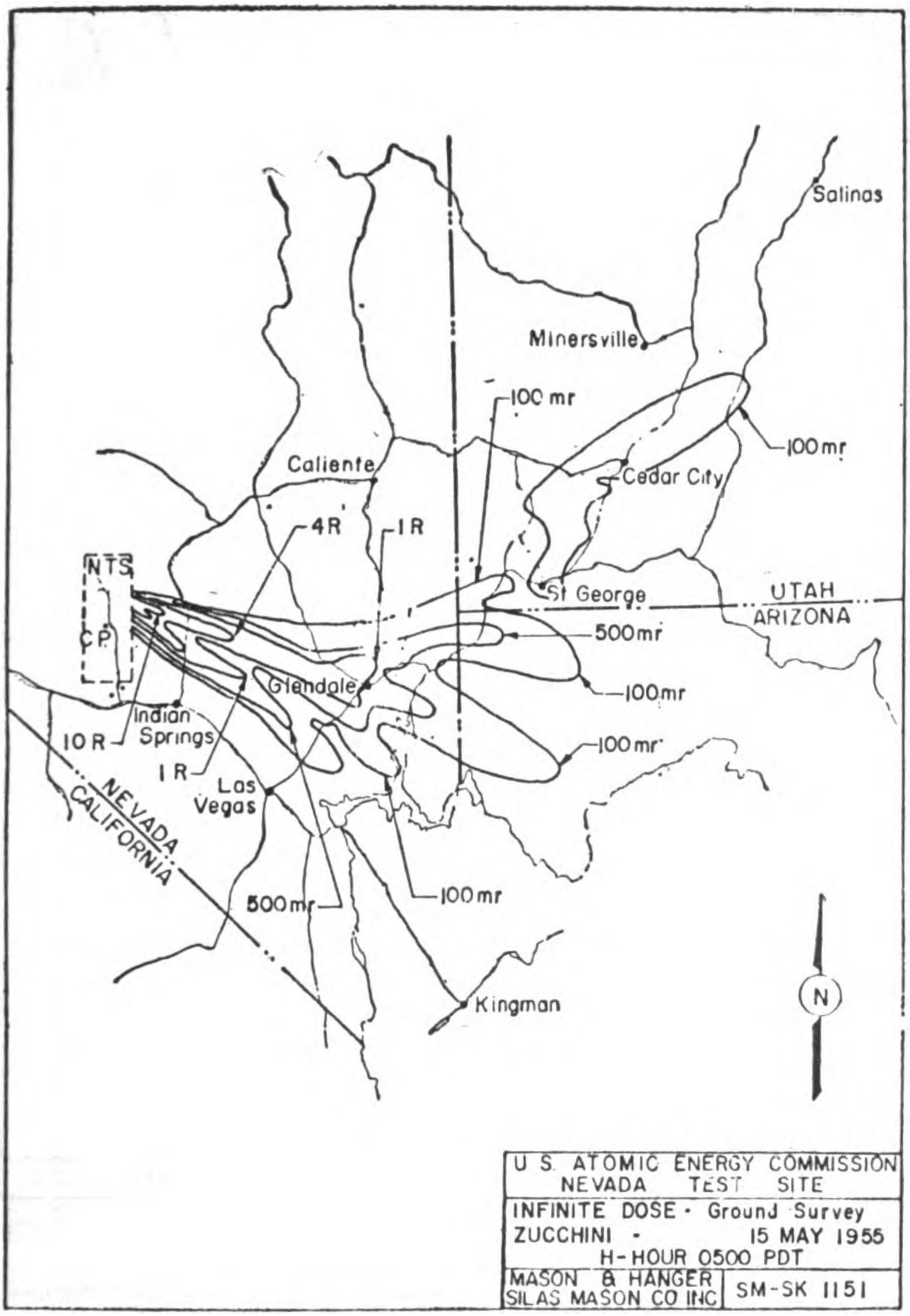
Location	Time of instrument reading (H+hours)	Gamma ground level (mr./hr.)	Time of fallout (H+hours)	Effective biological dose (mr.)	Infinite dose (mr.)
Populated areas:					
Warm Springs Ranch, Nev	3.4	50.0	3.4	470	850
Indian Springs, Nev	6.6	.18	1.2	4	6
Apex, Nev	4.1	6.5	3.5	75	140
Dry Lake, Nev	3.8	7.5	3.3	80	150
Crystal, Nev	3.5	11.0	3.5	100	190
Glendale, Nev	13.5	9.0	3.9	420	780
Moapa, Nev	3.9	65.0	3.6	700	1,290
Mesquite, Nev	12.0	3.0	6.0	110	210
Carp, Nev	4.8	.8	3.8	10	21
Logandale, Nev	5.3	20.0	4.5	290	540
Overton, Nev	5.6	17.0	4.7	260	480
Cedar City, Utah	7.0	4.8	6.6	90	170
Kanarraville, Utah	8.7	2.8	6.2	70	130
Pintura, Utah	9.0	2.2	5.9	55	110
Leeds, Utah	9.3	1.8	5.7	50	91
Washington, Utah	9.6	3.9	5.2	110	210
St. George, Utah	8.6	3.0	5.0	76	140
Summit, Utah	11.6	2.2	7.0	70	140
Parowan, Utah	11.7	5.5	7.3	180	350
Paragonah, Utah	11.8	4.6	7.4	150	300
Santa Clara, Utah	8.5	.8	4.8	20	38
Beaver Dam, Ariz	7.3	13.0	4.6	270	500
Nonpopulated points:					
U. S. 93, 12 miles north of junction with U. S. 91	3.1	82.0	3.1	700	1,270
7.5 miles south of Papoose Lake	32.7	85.0	0.5	19,900	32,500

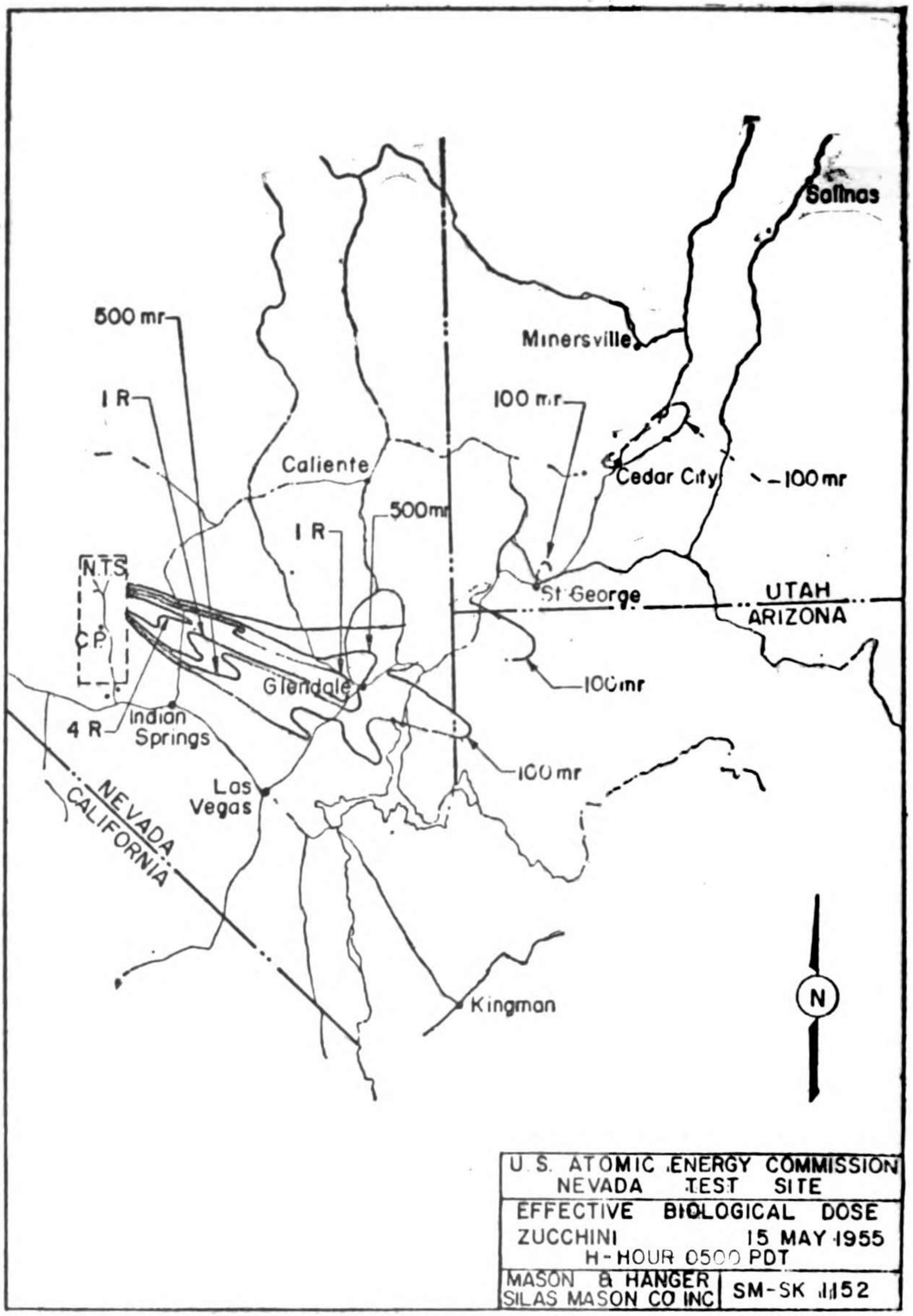

Salinas
Minersville
Caliente
Cedar City
4 R
N.T.S.
C.P.
St George
UTAH
ARIZONA
Glendale
I R
Indian Springs
Las Vegas
NEVADA
CALIFORNIA
Kingman
N
NOTE-
INFINITE DOSE PLOTTED.
U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
H Minus 0:30 FALLOUT PREDICTION
ZUCCHINI 15 MAY 1955
H-HOUR 0500 PDT
MASON & HANGER
SILAS MASON CO INC
SM-SK 1150


Salinas
Minersville
Cedar City
Caliente
St. George
UTAH
ARIZONA
N.T.S.
C.P.
Indian Springs
Glendale
Las Vegas
NEVADA
CALIFORNIA
Kingman
N
13,000' MSL
23,000' MSL
28,000' MSL
37,500' MSL Top of Cloud.
U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
CLOUD TRACK – ZUCCHINI
15 MAY 1955- H-HOUR 0500 PDT
MASON & HANGER
SILAS MASON CO. INC.
SM-SK 1148



Salinas
Minersville
1 R
4 R
10 R
Caliente
Cedar City
100 mr
N.T.S.
C.P.
St George
UTAH
ARIZONA
Glendale
Indian Springs
Las Vegas
NEVADA
CALIFORNIA
Kingman
N
NOTE - INFINITE DOSE PLOTTED.
U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
LOW LEVEL TERRAIN SURVEY
ZUCCHINI 15 MAY 1955
H-HOUR 0500 PDT
MASON & HANGER SILAS MASON CO. INC
SM-SK 1149


Salinas
Minersville
100 mr
100 mr
Caliente
Cedar City
4R
1 R
NTS
CP
St George
UTAH
ARIZONA
500mr
100mr
Glendale
Indian Springs
10 R
100 mr
1 R
Las Vegas
NEVADA
CALIFORNIA
500mr
100mr
Kingman
N
U S ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
INFINITE DOSE · Ground Survey
ZUCCHINI - 15 MAY 1955
H-HOUR 0500 PDT
MASON & HANGER
SILAS MASON CO INC
SM-SK 1151



6. SUMMARIES

In this section are summaries of the film badge program, accumulated dosage in populated areas, water and milk results, and air results. Each of these subjects is discussed in a subsection while accumulated dosage in populated areas is presented as table 2. The values presented are those measured by survey instruments and by film badges. Survey instrument readings have been expressed as effective biological dose and as infinite dose. Every populated place in which either type measurement was made is included.

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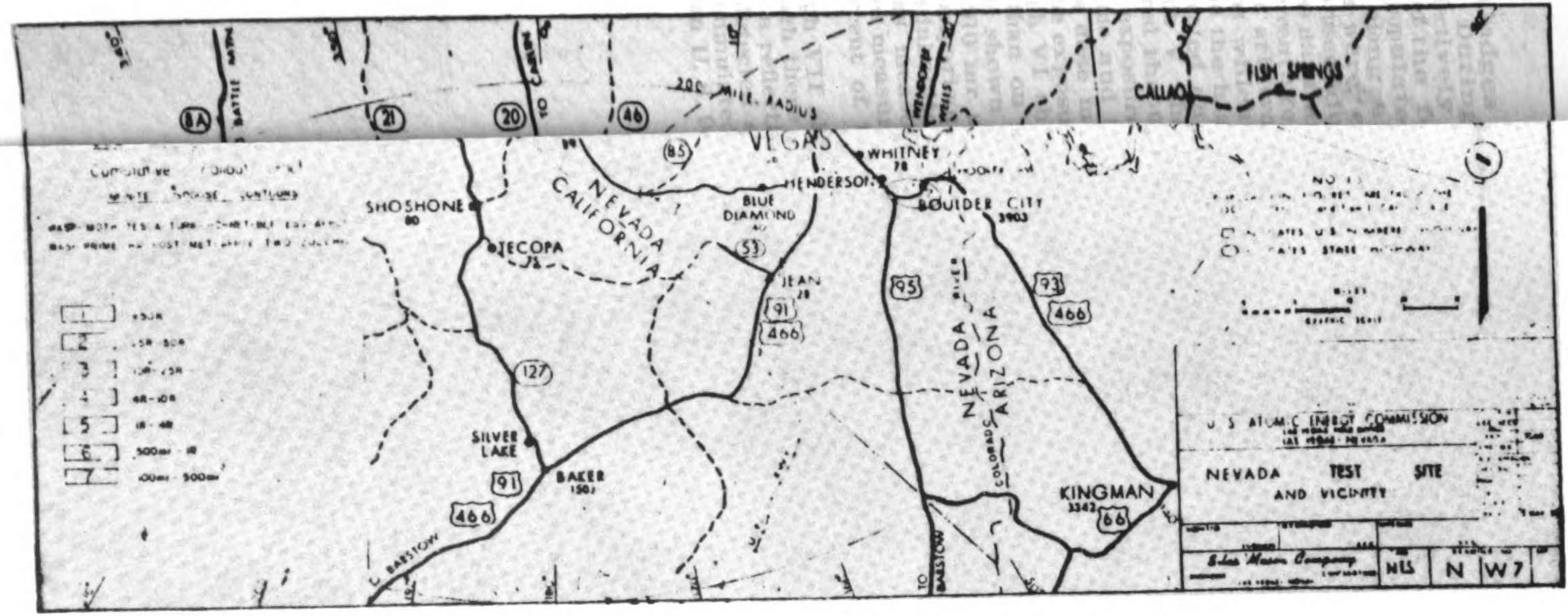


FILM BADGE PROGRAM

Film badges have proved to be a practical method for large-scale area monitoring. During Operation Teapot, an area of approximately 50,000 square miles was effectively monitored by the use of film badge stations. These stations consisted of the following categories: 171 worn by residents in the off-site area; 106 in populated areas; 152 inside and outside schools; and 126 at nonpopulated points along all of the major highways and most of the less-traveled roads. Badges were changed at frequent intervals, with a total of 4,420 individual badges used during the operation.

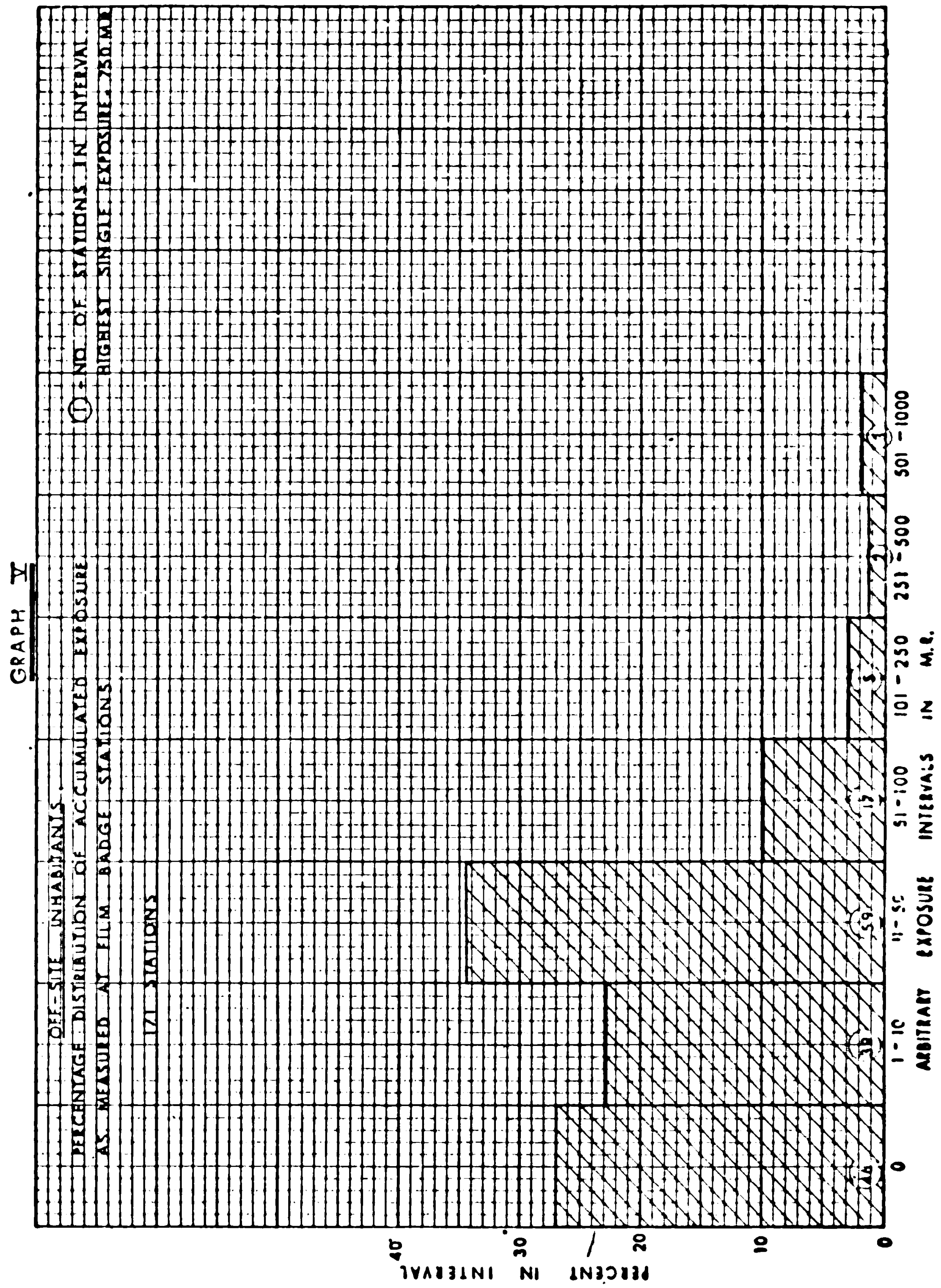
These data are summarized in five bar graphs, V through IX. In these graphs, the percentage of accumulated exposures for the test period which fall into various arbitrary exposure classifications are plotted. The actual number of stations which occur in a particular exposure interval are written into the bar and the highest accumulated exposure for a single station within a category is indicated on the graph.

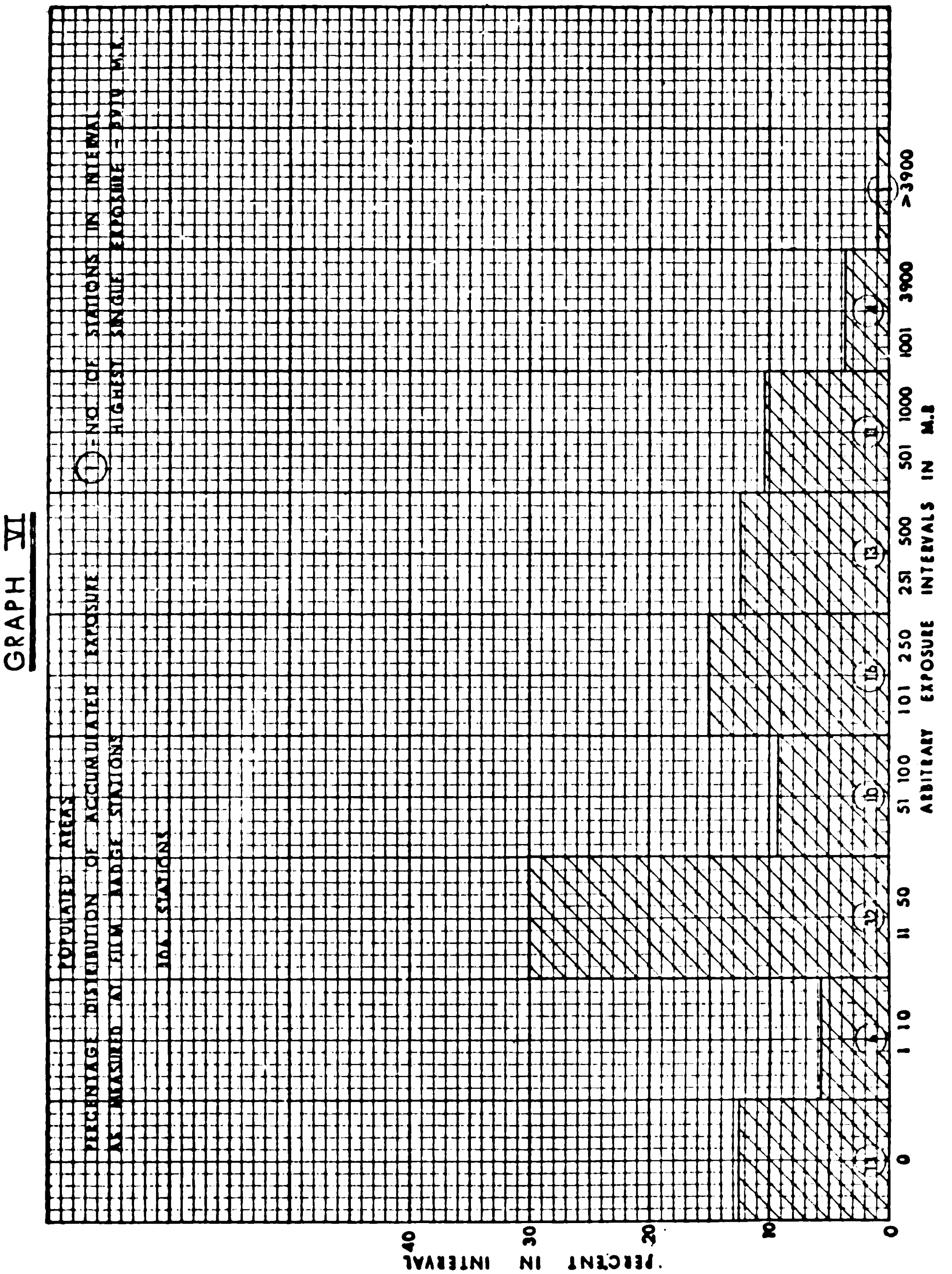
Graph V shows the accumulated dosages received by the 171 individuals scattered throughout the area who wore film badges. There were only 3 individual exposures greater than 500 mr for the test period. All of these occurred in Alamo and the highest was 750 mr. Since the records show that a portion of this dose may have been accumulated in Kawich Valley, it is more likely that the exposure at Alamo was around 600 mr.

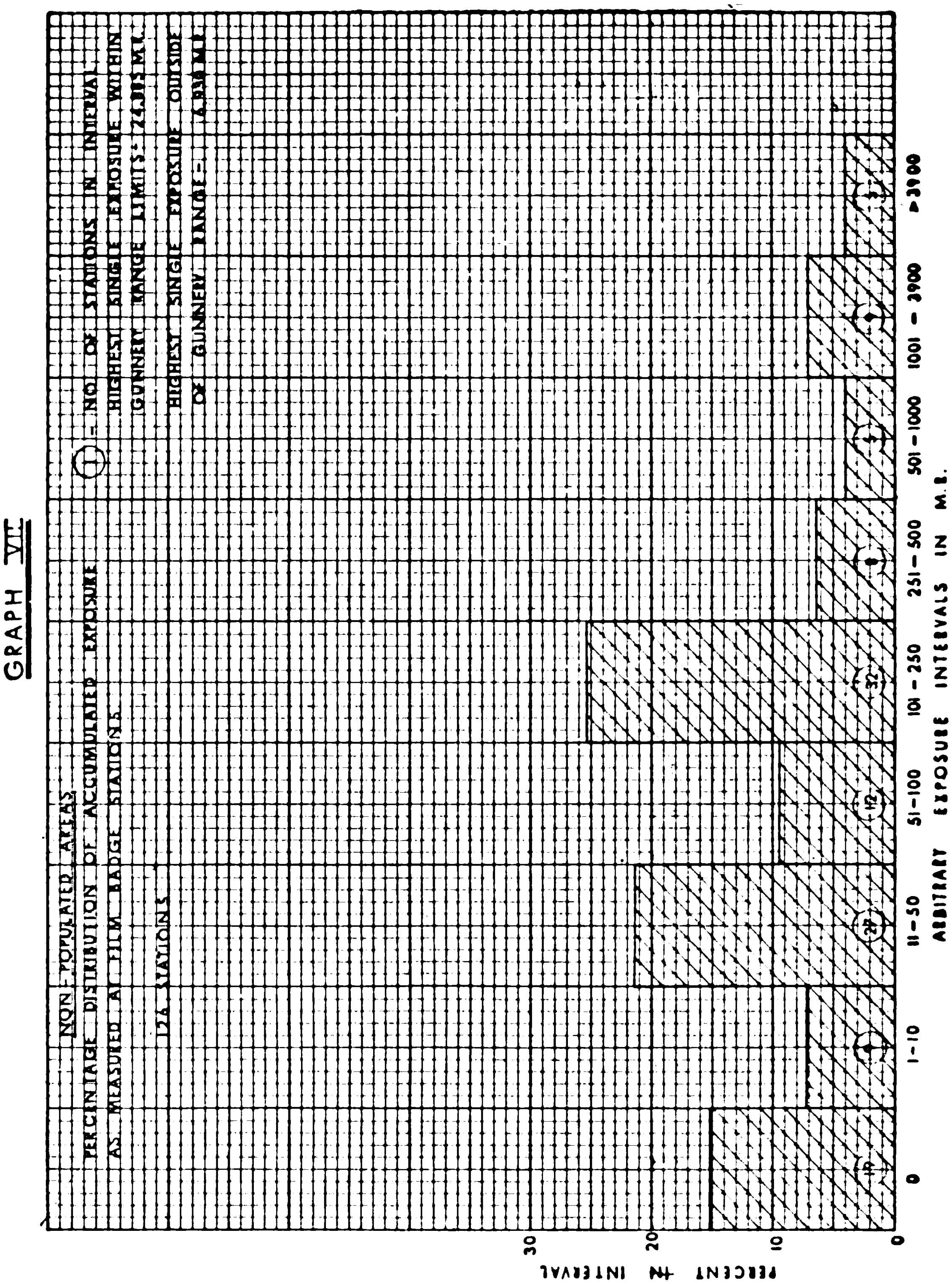
Graph VI shows the accumulated exposure as measured in populated areas other than on people. The range of exposures and the upper limit is greater than is shown on personnel badges. The highest single accumulated exposure was 3,910 mr at Elgin, Nev.

A comparison of graphs V and VI seems to indicate that the dosage received by the inhabitants of a particular area is less than the dose indicated for that area as measured by the same method. Approximately 94 percent of the dosages measured on people were within the 0 to 100 mr range and only about 57 percent of the exposures measured in these same areas were within this range.

Graph VII shows the accumulated exposure measured in unpopulated areas. Although there are a greater number of higher exposures noted in this category, this is a reflection of the higher close-in readings. Levels greater than 3,900 mr were detected at only one station beyond the gunnery range limits. This was an accumulated exposure for the test period of 6,930 mr at an uninhabited point on U. S. 93, 15 miles south of Alamo.

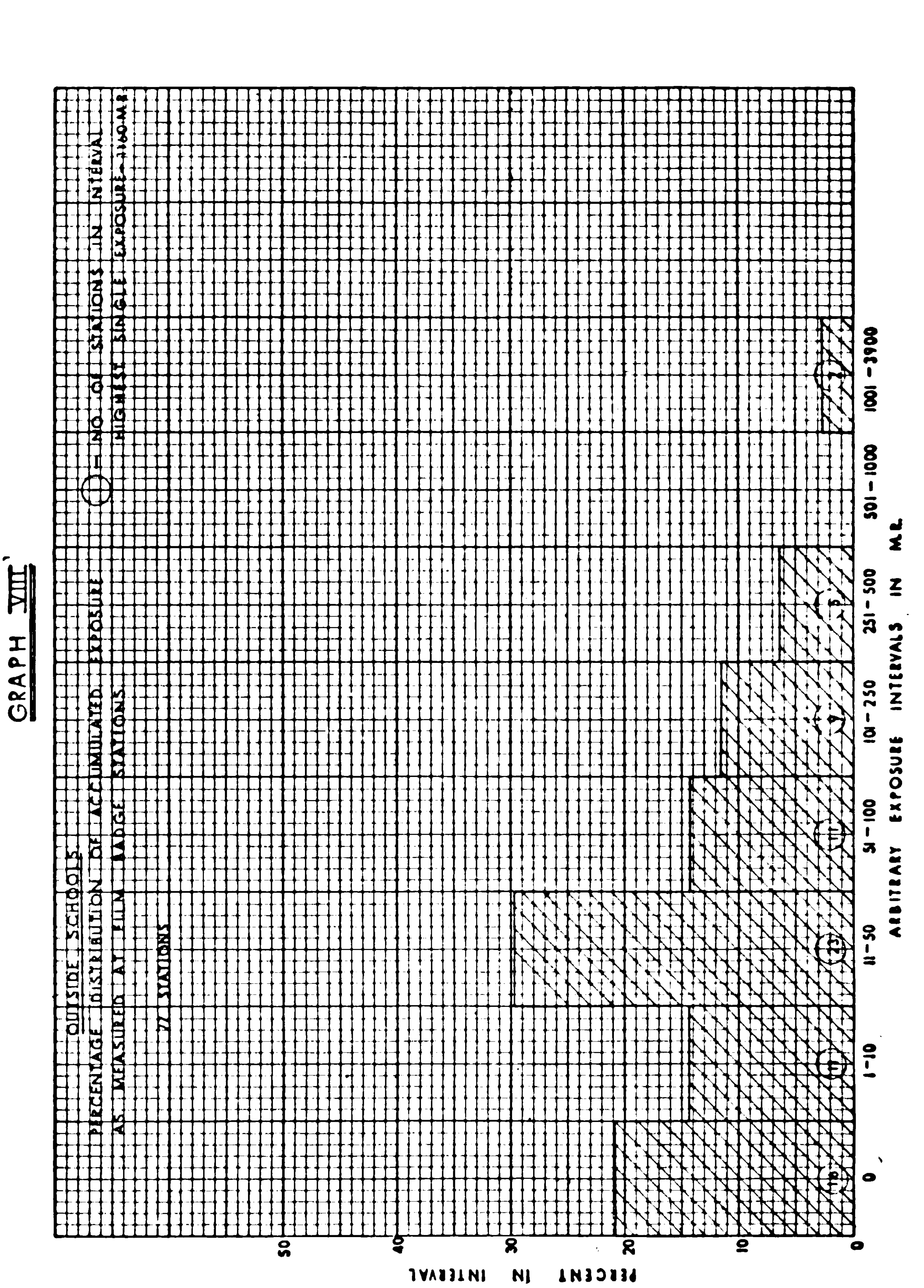

GRAPH V
OFF-SITE INHABITANTS
PERCENTAGE DISTRIBUTION OF ACCUMULATED EXPOSURE
AS MEASURED AT FILM BADGE STATIONS
171 STATIONS
(1) = NO. OF STATIONS IN INTERVAL
HIGHEST SINGLE EXPOSURE, 750 M.R.
PERCENT IN INTERVAL
0
10
20
30
40
0
1-10
11-50
51-100
101-250
251-500
501-1000
ARBITRARY EXPOSURE INTERVALS IN M.R.

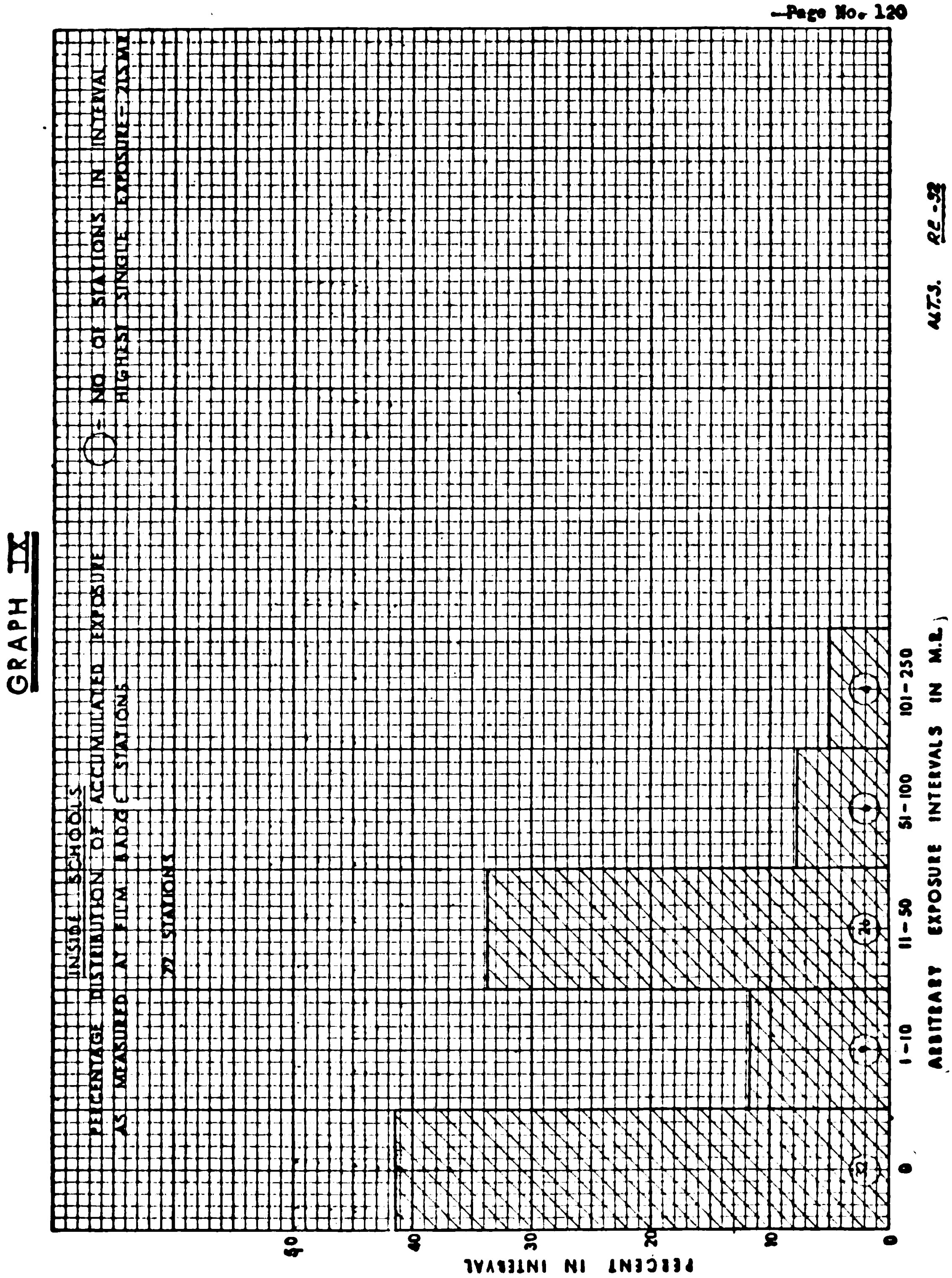

GRAPH VI
POPULATED AREAS
PERCENTAGE DISTRIBUTION OF ACCUMULATED EXPOSURE
AS MEASURED AT FILM BADGE STATIONS
104 STATIONS
NO. OF STATIONS IN INTERVAL
HIGHEST SINGLE EXPOSURE – 3910 M.R.
0
1 10
11 50
51 100
101 250
251 500
501 1000
1001 3900
>3900
ARBITRARY EXPOSURE INTERVALS IN M.R
0
10
20
30
40
PERCENT IN INTERVAL


GRAPH VII
NON-POPULATED AREAS
PERCENTAGE DISTRIBUTION OF ACCUMULATED EXPOSURE
AS MEASURED AT FILM BADGE STATIONS
126 STATIONS
1 - NO. OF STATIONS IN INTERVAL
HIGHEST SINGLE EXPOSURE WITHIN
GUNNERY RANGE LIMITS:
HIGHEST SINGLE EXPOSURE OUTSIDE
OF GUNNERY RANGE -
PERCENT IN INTERVAL
0
10
20
30
0
1-10
11-50
51-100
101-250
251-500
501-1000
1001-3900
>3900
ARBITRARY EXPOSURE INTERVALS IN M.R.
19
27
32

Graphs VIII and IX show the accumulated exposures outside and inside of schools, respectively. The highest exposure outside was 1,160 mr at Alamo and the highest inside exposure noted was at Fallini Ranch School. The significant feature of these graphs is the apparent protection afforded by school buildings. The upper exposure limit is reduced by a considerable factor on a gross basis and while about 95 percent of the inside exposures fall within the 0–100 mr range, only about 77 percent of the outside badges are so limited.

One other factor of interest should noted. When the badges are considered on an individual basis rather than by stations for the whole period, the percentage of negative badges becomes very large. The entire range of percentages for individual badges is tabulated below.


GRAPH VIII
OUTSIDE SCHOOLS
PERCENTAGE DISTRIBUTION OF ACCUMULATED EXPOSURE
AS MEASURED AT FILM BADGE STATIONS
77 STATIONS
= NO. OF STATIONS IN INTERVAL
HIGHEST SINGLE EXPOSURE
PERCENT IN INTERVAL
0
10
20
30
40
50
0
1-10
11-50
51-100
101-250
251-500
501-1000
1001-2900
ARBITRARY EXPOSURE INTERVALS IN M.R.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GRAPH IX
INSIDE SCHOOLS
PERCENTAGE DISTRIBUTION OF ACCUMULATED EXPOSURE
AS MEASURED AT FILM BADGE STATIONS
○ = NO. OF STATIONS IN INTERVAL
HIGHEST SINGLE EXPOSURE
0
1-10
11-50
51-100
101-250
ARBITRARY EXPOSURE INTERVALS IN M.R.
PERCENT IN INTERVAL
0
10
20
30
40
50
32
26

Range interval, mr	Category in percent				
	Personnel exposure	Populated places	Unpopulate areas	Schools	
				Outside	Inside
0	82.8	71.6	67.7	79.1	89.2
1-10	8.9	8.5	8.2	9.3	4.8
11-50	6.7	11.3	12.7	7.3	5.1
51-100	.6	2.8	3.0	2.0	.6
101-250	.6	2.8	4.2	1.5	.3
251-500	.4	1.8	1.3	.5	
501-1,000		.7	1.1	.3	
1,001-3,900		.5	1.2		
3,900			.6		

If one considers the extensive area covered during Operation Teapot, the total number of badges and the large number of badge stations, and the numbers of people wearing badges off site, then film badge monitoring would appear to have the following desirable characteristics:

1. Film badges offer a permanent record of accumulated radiation exposure.
2. The exposure measurements obtained from film badges are not subject to error due to mathematical manipulation.
3. Film badges are convenient to use.
4. Extensive areas can readily be monitored by the use of film badges.
5. Film badges require no attention during the time they are recording radiation exposure.
6. From all available information, it appears that film badges can be left in the field for extended periods without adversely affecting the accumulated exposure data obtained.
7. People wearing film badges have a positive feeling that steps are being taken to look after their welfare. The typical attitude seemed to be twofold: (*a*) that they were important enough to be considered; and (*b*) the feeling of being protected.
8. Film badge records have an official status in radiation protection programs.

Based on performance during Operation Teapot, film badges are an effective, practical, and economical way to monitor both extensive land areas and people during a continental test series.

Inevitably, when data which presumably measure the same thing are collected, a comparison of results seems indicated. Comparative data at film badge stations in the Lincoln Mine zone are shown in the following table for illustrative purposes. The results shown are given in terms of effective biological dose, infinite dose, and accumulated dose as measured on film badges.

If one were to draw conclusions, these could only be broad generalizations, such as that the film dosage is *roughly comparable to the effective biological dose.* Striking exceptions are apparent. To attempt to be more specific, as for example, trying to arrive at a valid, constant factor relating the various types of data is not warranted. The reasons for this are outlined below. All of these various data, however, are useful and the fact that they cannot be strictly correlated does not impair their individual value for various purposes.

Film badges and monitoring data do not measure exactly the same thing although it might seem so at first glance. The measurements made by these various methods might be stated as follows:

Film badge results are a measure of the total accumulated radiation exposure within a given energy range, at a fixed point, and for a given time interval. This time is generally the period of the test series plus a week or two prior to and after the series.

Comparison of accumulated dosage readings in the Lincoln Mine area

Film badge station	Monitoring results: Effective biological dose, milliroentgen	Monitoring results: Infinite dose, milliroentgen	Film badge dose, milliroentgen	Film badge station	Monitoring results: Effective biological dose, milliroentgen	Monitoring results: Infinite dose, milliroentgen	Film badge dose, milliroentgen
74	717	1,197	450	127	26	47	180
75	2,087	3,567	2,000	128	5,100	8,830	7,330
76	105	190	180	129	84	146	250
80	200	370	245	130	29,295	48,395	24,650
88	1,801	3,340	2,110	131	5,015	8,290	11,940
89	2,135	3,903	2,320	132	1,037	1,765	2,100
90	7	13	1,625	133	6,562	11,120	24,885
91	79	146	200	134	95	168	115
92	200	360	140	135	2,247	4,070	3,370
93	94	168	180	141	500	930	515
94	367	625	360	143	2,580	4,590	2,990
126	52	105	100	476	81	133	235

Infinite dose is the maximum calculated exposure from time of fallout to infinite time at the place of measurement, based on an instrument reading taken at that place and extrapolated to infinity.

Effective biological dose is a percentage of the infinite dose obtained by inserting certain impirical factors for shielding, weathering, etc.

The reasons why these various means of estimating accumulated dose are not absolutely comparable are:

1. Both EBD and film badge doses are a variable percentage of the infinite dose. The relationship of EBD to infinite dose varies from approximately 60 percent when the time of fallout is 30 minutes to about 50 percent when the time of fallout is 9 hours. The relationship of film badge exposure to infinite dose varies with the total time interval covered by the film badge series, at a particular point.
2. Infinite dose and EBD are mathematical extrapolations of a single reading by instruments, which will vary with the accuracy of the reading and the approximation of fallout time.
3. Dosage determination by film badge measurements does not require a knowledge of fallout time. Film badges measure directly the actual dose present at a point during the time of exposure If changes in radiation level occur during this time, such as the blowing away or covering up of radioactive material or the secondary deposition of radioactive material at a later time, these changes are reflected in the film badge readings but not in the infinite dose or EBD results.
4. When two closely spaced shots proceed in the same direction, the monitoring readings from the second shot may reflect residual radioactivity from the previous shot. Extrapolation of the readings may result in higher infinite dose and EBD.
5. Fallout patterns are directional and frequently sharply defined within a given area. Unless the monitoring reading is taken at the exact point of film badge exposure, the results cannot be compared.
6. It is possible to fail to record a significant portion of the total exposure on film badges by discontinuing the program too soon. This would only occur under special circumstances. These would be a situation in a close-in area where the major portion of the exposure occurred on the last shot and the badges were collected immediately thereafter. It could be theoretically possible to fail to record several hundred mr. of total exposure under these conditions. It does not appear, however, that this could be too much of a factor beyond the gunnery range limits.
7. Film badges are a positive means of measurement of personnel exposure, Where film badges are worn by people, they measure the actual dose received as these people move about in their daily routine. As far as the individual's exposure is concerned, it is unnecessary to speculate as to his probable location to know his exposure, as is necessary when using monitoring measurements.

The above material indicates that monitoring and film badge measurements are both necessary and supplementary data. The overall picture of the total ex-

posure resulting from either type of data is similar in nature, but it is impractical to attempt to relate the two types of measurement through some specific and constant factor or factors.

The large amount of data that can be obtained with relative ease and economy by film badge measurements indicates that these measurements should become a permanent part of offsite planning. The major change that should be instituted is to increase the area coverage (school and personnel coverage was probably adequate) and at the same time to reduce the workload by less frequent badge changes.

Although the offsite program was concerned primarily with exposures of people and animals, numerous close-in monitoring runs were made to aid the Fallout Prediction Unit. In future operations, this assistance could be supplemented by lines of film badges across the gunnery range to aid in this objective.

Aside from the items mentioned above, and minor details regarding record-keeping, the film badge program as operated was so successful and so productive that it appears that future programs should be based on the same general plan.

TABLE 2.—*Accumulated dosage in populated areas*

Location	Effective biological dose (mr.)	Infinite dose (mr.)	Film badge record	
			Time interval	Accumulated dosage (mr.)
Acoma, Nev			Apr. 1-May 16	[1] 3,130
Adaven, Nev	200	370	Mar. 11-May 16	[1] 245
Alamo, Nev	1,359	2,407	Feb. 12-June 7	1,160
Alton, Utah	19	37		
Anderson Junction, Utah	34	69	Feb. 11-May 20	20
Apex, Nev	75	140	Feb. 11-June 7	110
Ash Springs, Nev	142	264		
Austin, Nev			Feb. 12-May 19	40
Baker, Nev	148	303	Feb. 11-May 23	[2] 40
Barclay, Nev			Feb. 12-May 16	1,860
Bear Valley Junction, Utah			Feb. 11-May 21	390
Beatty, Nev			Feb. 21-May 17	[1] 50
Beaver, Utah	270	540	Feb. 14-May 23	100
Beaver Dam, Ariz	300	560	Feb. 11-June 10	145
Beryl, Utah	102	200	Feb. 21-May 20	50
Beryl Junction, Utah	456	870	Feb. 14-May 20	635
Boulder City, Nev	83	156	Feb. 12-May 17	30
Bristol Silver Mine, Nev			Feb. 21-May 17	[1] 20
Buckhorn Ranch, Nev	980	1,750		
Bunkerville, Nev	19	37	Feb. 11-June 10	25
Caliente, Nev	320	609	Feb. 14-May 16	370
Carp, Nev	20	41	Feb. 10-June 15	60
Caselton, Nev			Feb. 11-May 16	0
Cedar City, Utah	144	274	Feb. 11-May 20	20
Central, Utah			Mar. 24-May 20	[1] 0
Clarks Station, Nev			Feb. 11-May 21	10
Cove Fort, Utah	29	58	Feb. 14-Mar. 10	[1] 0
Crestline, Nev			Feb. 11-May 16	450
Crystal, Nev	107	203	Feb. 11-June 7	60
Crystal Springs, Nev	50	91		
Currant, Nev	212	429	Feb. 11-May 21	295
Desert Rock, Nev	47	96		
Dry Lake, Nev	210	385	Feb. 11-June 7	245
Duckwater, Nev	300	590	Feb. 11-May 21	345
East Ely, Nev			Feb. 12-May 9	[1] 205
Elgin, Nev	2,880	5,340	Feb. 14-May 24	3,910
Ely, Nev	328	653	Feb. 12-May 9	[1] 205
Enterprise, Utah	182	344	Feb. 14-May 20	220
Eureka, Nev	18	36	Feb. 11-May 19	[2] 70
Fallini Ranch, Nev	250	460	Feb. 12-May 16	395
Frisco, Utah	17	35		
Garrison, Utah	94	191	Feb. 11-May 23	15
Glendale, Nev	738	1,392		
Glendale, Utah	19	37	Feb. 11-May 19	10
Goldfield, Nev			Feb. 10-May 18	0
Groom Mine, Nev			Feb. 12-May 14	[1] 345
Gunlock, Utah	8	17	Feb. 11-May 20	20
Hamilton Fort, Utah	95	180		
Hamlin Valley, Utah			Feb. 20-May 20	0
Harrisburg Junction, Utah			Feb. 11-May 19	75
Henderson, Nev	8	15		
Hiko, Nev	63	110	Feb. 11-May 16	150
Hoover Dam, Nev	11	20		
Hurricane, Utah	51	100	Feb. 11-May 19	20

See footnotes at end of table.

TABLE 2.—*Accumulated dosage in populated areas*—Continued

Location	Effective biological dose (mr.)	Infinite dose (mr.)	Film badge record	
			Time interval	Accumulated dosage (mr.)
Indian Springs, Nev	12	22	Feb. 11–May 18	70
Kanab, Utah	----	----	Feb. 11–May 19	10
Kanarraville, Utah	220	420	Feb. 11–May 20	50
Kimberley, Nev	----	----	do	110
Lake Mead Base, Nev	16	30	----	----
Las Vegas, Nev	140	260	Feb. 11–May 17	30
Lathrop Wells, Nev	21	42	Feb. 11–May 16	0
Leeds, Utah	94	179	Feb. 11–May 20	10
Lincoln Mine, Nev	62	116	Feb. 14–May 16	100
Littlefield, Ariz	10	20	Feb. 11–June 10	160
Lockes Ranch, Nev	662	1,289	Feb. 11–May 21	77
Logandale, Nev	307	573	Feb. 11–May 10	[1] 230
Lund, Nev	513	1,012	Feb. 11–May 21	315
Lund, Utah	----	----	Feb. 11–May 20	545
Manhattan, Nev	----	----	Feb. 11–May 10	[1] 20
McGill, Nev	16	32	Feb. 12–May 20	80
Mercury, Nev	42	84	----	----
Mesquite, Nev	120	229	Feb. 11–May 10	[1] 20
Milford, Utah	70	140	Feb. 12–May 23	120
Millet, Nev	----	----	Feb. 11–May 19	30
Minersville, Nev	170	330	Feb. 12–May 23	200
Moapa, Nev	890	1,653	Feb. 11–June 7	865
Modena, Utah	99	190	Feb. 14–May 20	40
Moon River, Nev	----	----	Feb. 11–May 21	0
Mount Carmel Junction, Utah	----	----	Feb. 11–May 19	50
Nellis, Nev	31	56	----	----
North Las Vegas, Nev	192	357	----	----
Newcastle, Utah	182	354	----	----
New Harmony, Utah	59	110	Feb. 11–May 20	10
Nyala, Nev	500	930	Mar. 10–May 16	[1] 515
Orderville, Utah	19	37	Feb. 11–May 19	30
Overton, Nev	260	480	Feb. 11–June 10	160
Pahrump, Nev	3	6	Feb. 21–May 16	[1] 260
Panaca, Nev	149	283	Feb. 11–May 17	100
Paragonah, Utah	166	332	Feb. 11–May 21	120
Parowan, Utah	185	360	Feb. 11–May 12	[1] 20
Peavine, Nev	----	----	Feb. 11–May 19	40
Pintura, Utah	55	110	Mar. 4–May 20	[1] 20
Pioche, Nev	26	51	Feb. 11–May 16	20
Preston, Nev	80	172	Feb. 11–May 21	160
Quartz Mine, Nev	35	71	----	----
Reed, Nev	2,580	4,590	May 5–16	[1] 2,990
Riverside, Nev	43	84	Feb. 11–June 10	390
Rockville, Utah	3	6	Feb. 11–May 19	20
Round Mountain, Nev	34	74	do	10
Ruth, Nev	----	----	Feb. 11–May 20	60
Santa Clara, Utah	197	388	do	0
St. George, Utah	179	350	Feb. 14–May 19	40
Shoshone, Calif	----	----	Apr. 12–May 16	[1] 20
Springdale, Nev	----	----	Feb. 11–May 17	20
Springdale, Utah	----	----	Feb. 11–May 19	60
Strawberry, Nev	----	----	do	20
Summit, Utah	70	140	Feb. 11–May 21	30
Sunnyside, Nev	5	10	do	20
Tenopah, Nev	----	----	Feb. 10–May 10	[1] 10
Toquerville, Utah	63	129	Feb. 11–May 19	30
Ursine, Nev	19	40	Feb. 11–May 16	10
Veyo, Utah	14	27	Feb. 11–May 20	10
Virgin, Utah	----	----	Feb. 11–May 10	[1] 10
Warm Springs, Nev	183	335	Feb. 11–May 19	190
Warm Springs Ranch, Nev	567	1,034	Feb. 11–June 7	880
Washington, Utah	197	385	Feb. 11–May 19	30
Whitney, Nev	8	15	----	----
Zane, Utah	275	525	----	----

[1] Interval covered by film badges did not include entire test period.
[2] A badge is missing, which may have added significantly to the total dose.

WATER AND MILK RESULTS

In tables 3 and 4 are presented selected results from radioactivity analysis of water and milk, respectively. The data are selective in that only results where the radioactivity concentration exceeded 10^{-5} μc/ml. at the time of collection are shown. During the series, a total of 149 water and 134 milk samples were processed.

The background concentration for water was 6.8×10^{-7} μc/ml. This average is based on the analysis of 30 samples. The background concentration for milk,

as determined from 21 samples was 1.8×10^{-6} $\mu c/ml$. These background samples were collected and analyzed prior to the start of the test series and the data presented are gross values.

Relative information can be obtained by comparing the respective background value with the data presented in the appropriate table. However, there are several factors which should be understood before making such a comparison. Such factors would include:

1. Background values are gross figures. In other words, there may be differences in background from one type source to another and from one area to another.
2. Extrapolation by the 1.2 decay law is not completely valid as radioactive materials are removed from water selectively and similar selectivity takes place when radioactive materials are metabolized by an animal. Therefore, the tabulated values are in all probability conservative.
3. Time of fallout in large lakes and running streams is difficult to determine.
4. Time of fallout as well as time and method of contamination for use in calculations involving milk samples is practically impossible to determine without exhaustive specialized study.

TABLE 3.—*Radioactivity concentration in water*

Location	Detonation which produced fallout	Activity at time of collection (uc/ml)	Activity at time of fallout (uc/ml)
Upper Pahranagat Lake	Met	2.4×10^{-4}	3.0×10^{-3}
Maynard Lake	do	1.0×10^{-3}	1.2×10^{-2}
Meadow Valley wash	do	5.7×10^{-4}	1.1×10^{-3}
Maynard Lake	do	1.4×10^{-4}	7.1×10^{-3}
Crystal Springs, Nev	do	6.0×10^{-5}	1.8×10^{-4}
Meadow Valley wash	Apple	4.6×10^{-5}	1.5×10^{-3}
Cedar City, Utah (melted snow)	do	1.3×10^{-4}	1.3×10^{-4}
Waterhole at Groom Rd. and Nevada Hwy. 25	do	1.3×10^{-4}	6.0×10^{-3}
Waterhole at north end Papoose Lake	do	1.4×10^{-5}	2.8×10^{-3}
Upper Pahranagat Lake	Apple Two	2.6×10^{-5}	5.7×10^{-5}
Crystal Springs, Nev	do	1.6×10^{-5}	3.7×10^{-5}
Upper Pahranagat Lake	do	2.8×10^{-5}	6.3×10^{-5}
Virgin River at Riverside, Nev	Ess	3.8×10^{-5}	2.0×10^{-4}
Lake at Beaver Dam, Ariz	do	9.1×10^{-5}	3.2×10^{-4}
Groom Lake	Tesla	6.2×10^{-5}	3.2×10^{-3}
Waterhole at north end Papoose Lake	do	2.8×10^{-5}	3.3×10^{-3}
St. George, Utah, tapwater	Post	1.3×10^{-5}	2.9×10^{-6}
Leeds, Utah, tapwater	do	1.0×10^{-5}	2.0×10^{-5}
Irrigation water near Warm Springs, Nev	Hornet	1.1×10^{-5}	3.1×10^{-5}
Cedar City, Utah, tapwater	Zucchini	2.0×10^{-4}	1.2×10^{-3}
Central, Utah, Reservoir	do	5.4×10^{-5}	5.4×10^{-4}
Leeds, Utah, tapwater	do	1.2×10^{-5}	8.8×10^{-4}
Waterhole at Groom Rd. and Nevada Hwy. 25	do	4.3×10^{-5}	2.3×10^{-3}
Beaver Dam, Ariz., Lake	do	1.7×10^{-5}	1.9×10^{-4}
Virgin River at Riverside, Nev	do	1.3×10^{-4}	8.3×10^{-4}
Upper Pahranagat Lake	do	6.0×10^{-5}	9.8×10^{-5}
Creek at Ursine, Nev	do	1.9×10^{-5}	2.2×10^{-4}
Cedar City, Utah (melted hail)	do	1.6×10^{-2}	1.6×10^{-1}
Lake Mead at Stewart's Point	do	1.0×10^{-5}	8.3×10^{-5}
Meadow Valley wash	do	1.5×10^{-5}	1.7×10^{-4}

TABLE 4.—*Radioactivity concentration in milk*

Location	Detonation which produced fall out (probable)	Activity at time of collection (uc/ml)
Alamo, Nev. (ranch)	Moth	1.3×10^{-5}
Hiko, Nev. (ranch)	do	1.2×10^{-5}
Alamo, Nev. (ranch)	Turk	1.3×10^{-5}
Do	Met	4.9×10^{-5}
Do	do	4.9×10^{-5}
Beaver, Utah (dairy)	Tesla	1.5×10^{-5}
Minersville, Utah (dairy)	Post	4.0×10^{-5}
Do	Met	1.0×10^{-5}
Beaver, Utah (dairy)	do	1.3×10^{-5}
Cedar City, Utah (dairy)	do	1.3×10^{-4}
Ely, Nev. (ranch)	Tesla	1.9×10^{-5}
Ely, Nev. (dairy)	Ess	1.2×10^{-5}
Do	Met	1.0×10^{-5}

AIR RESULTS

Table 5 is a summary of all the air analyses obtained during Teapot. The location of air samplers, the dates and times of sampler operation, and the radioactivity concentration expressed as $\mu c/m^3$. averaged over the sampling period are given for each detonation. Values of 10^{-6} $\mu c/m^3$. and less are in the range of normal air-radioactivity backgrounds measured before and during the operation. Therefore, results less than 10^{-6} $\mu c/m^3$. are not listed other than as 10^{-6} $\mu c/m^3$.

TABLE 5.—*Airborne radioactivity concentrations*

SHOT: WASP

Location	Sampling period		Activity uc/m³
	From—	To—	
Alamo, Nev	1125, Feb. 18	1510, Feb. 18	10^{-6}
Caliente, Nev	1218, Feb. 18	2220, Feb. 18	2.0×10^{-6}
Cedar City, Utah	1130, Feb. 18	1200, Feb. 19	5.0×10^{-6}
Currant, Nev	1130, Feb. 18	1500, Feb. 18	10^{-6}
Ely, Nev	1130, Feb. 18	1730, Feb. 18	10^{-6}
Eureka, Nev	1108, Feb. 18	1212, Feb. 19	10^{-6}
Glendale, Nev	1200, Feb. 18	2330, Feb. 18	10^{-6}
Indian Springs, Nev	1200, Feb. 18	2025, Feb. 18	6.6×10^{-5}
Las Vegas, Nev	1200, Feb. 18	2400, Feb. 18	10^{-6}
Lincoln Mine, Nev	1200, Feb. 18	1600, Feb. 18	10^{-6}
Mercury, Nev	1204, Feb. 18	2125, Feb. 18	1.2×10^{-6}
Mesquite, Nev	1300, Feb. 18	1700, Feb. 18	10^{-6}
Nellis, Nev	1200, Feb. 18	2400, Feb. 18	3.3×10^{-6}
Pioche, Nev	1215, Feb. 18	2315, Feb. 18	10^{-6}
St. George, Utah	1125, Feb. 18	1135, Feb. 19	1.6×10^{-6}
Tonopah, Nev	0800, Feb. 18	2000, Feb. 18	10^{-6}

SHOT: MOTH

Location	From—	To—	Activity uc/m³
Alamo, Nev	0620, Feb. 22	0850, Feb. 23	3.2×10^{-4}
Beaver, Utah	0545, Feb. 22	0845, Feb. 23	8.1×10^{-5}
Caliente, Nev	0540, Feb. 22	1745, Feb. 22	4.9×10^{-4}
Cedar City, Utah	1755, Feb. 22	0945, Feb. 23	4.4×10^{-2}
Currant, Nev	0620, Feb. 22	1004, Feb. 23	10^{-6}
Ely, Nev	0545, Feb. 22	0945, Feb. 23	1.9×10^{-6}
Glendale, Nev	0530, Feb. 22	0945, Feb. 23	1.2×10^{-3}
Indian Springs, Nev	0545, Feb. 22	0700, Feb. 23	1.0×10^{-5}
Las Vegas, Nev	0545, Feb. 22	1730, Feb. 22	7.9×10^{-6}
Lincoln Mine, Nev	0545, Feb. 22	2315, Feb. 22	8.8×10^{-6}
Mercury, Nev	0400, Feb. 22	1125, Feb. 22	10^{-6}
Mesquite, Nev	0600, Feb. 22	0945, Feb. 23	4.8×10^{-4}
Nellis, Nev	0545, Feb. 22	1700, Feb. 22	7.2×10^{-5}
Pioche, Nev	0600, Feb. 22	1000, Feb. 23	9.9×10^{-5}
St. George, Utah	0530, Feb. 22	0545, Feb. 23	2.8×10^{-4}
Tonopah, Nev	0630, Feb. 22	0750, Feb. 23	5.7×10^{-6}

SHOT: TESLA

Location	From—	To—	Activity uc/m³
Alamo, Nev	0530, Mar. 1	0520, Mar. 2	2.2×10^{-2}
Beaver, Utah	0530, Mar. 1	0530, Mar. 2	6.1×10^{-4}
Caliente, Nev	0530, Mar. 1	0930, Mar. 2	1.9×10^{-3}
Cedar City, Utah	0530, Mar. 1	0530, Mar. 2	6.7×10^{-6}
Ely, Nev	0525, Mar. 1	0930, Mar. 2	5.1×10^{-4}
Glendale, Nev	0515, Mar. 1	0515, Mar. 2	2.7×10^{-5}
Indian Springs, Nev	0530, Mar. 1	0530, Mar. 2	4.6×10^{-5}
Las Vegas, Nev	0520, Mar. 1	0730, Mar. 2	3.2×10^{-6}
Lincoln Mine, Nev	0530, Mar. 1	0930, Mar. 2	6.5×10^{-4}
Mercury, Nev	0400, Mar. 1	0405, Mar. 2	4.3×10^{-6}
Mesquite, Nev	0530, Mar. 1	0530, Mar. 2	7.8×10^{-5}
Nellis, Nev	0530, Mar. 1	0530, Mar. 2	1.3×10^{-5}
Pioche, Nev	0550, Mar. 1	0930, Mar. 2	1.8×10^{-3}
St. George, Utah	0540, Mar. 1	0930, Mar. 2	4.0×10^{-2}
Tonopah, Nev	0500, Mar. 1	0630, Mar. 2	3.4×10^{-6}

TABLE 5.—*Airborne radioactivity concentrations*—Continued

SHOT: TURK

Location	Sampling period		Activity uc/m³
	From—	To—	
Alamo, Nev	0530, Mar. 7	1320, Mar. 8	5.6×10^{-6}
Beaver, Utah	0520, Mar. 7	1620, Mar. 8	5.9×10^{-4}
Currant, Nev	0607, Mar. 7	1050, Mar. 8	1.7×10^{-6}
Ely, Nev	0525, Mar. 7	0900, Mar. 8	1.4×10^{-6}
Eureka, Nev	0645, Mar. 7	2000, Mar. 7	10^{-6}
Indian Springs, Nev	0545, Mar. 7	0700, Mar. 8	7.6×10^{-4}
Las Vegas, Nev	0520, Mar. 7	1000, Mar. 8	1.6×10^{-4}
Lincoln Mine, Nev	0520, Mar. 7	0920, Mar. 8	3.3×10^{-6}
Mercury, Nev	0400, Mar. 7	1020, Mar. 8	1.7×10^{-6}
Nellis, Nev	0520, Mar. 7	0920, Mar. 8	6.7×10^{-6}
Pioche, Nev	0545, Mar. 7	1000, Mar. 8	9.8×10^{-4}
St. George, Utah	0515, Mar. 7	1145, Mar. 8	1.5×10^{-4}
Beatty, Nev	0800, Mar. 7	0820, Mar. 8	8.7×10^{-6}
Barstow, Calif	0510, Mar. 7	1530, Mar. 7	10^{-4}
Lund, Nev	0545, Mar. 7	0950, Mar. 8	1.4×10^{-6}

SHOT: HORNET

Location	From—	To—	Activity uc/m³
Alamo, Nev	0600, Mar. 12	0910, Mar. 13	3.0×10^{-3}
Beaver, Utah	0520, Mar. 12	0920, Mar. 13	2.5×10^{-3}
Caliente, Nev	0525, Mar. 12	0920, Mar. 13	8.8×10^{-4}
Cedar City, Utah	0520, Mar. 12	1220, Mar. 13	2.7×10^{-3}
Ely, Nev	0520, Mar. 12	0920, Mar. 13	7.8×10^{-4}
Glendale, Nev	0520, Mar. 12	0920, Mar. 13	1.2×10^{-2}
Indian Springs, Nev	0530, Mar. 12	1007, Mar. 13	4.8×10^{-6}
Las Vegas, Nev	0520, Mar. 12	0920, Mar. 13	2.0×10^{-5}
Lincoln Mine, Nev	0520, Mar. 12	0920, Mar. 13	3.3×10^{-5}
Mercury, Nev	0520, Mar. 12	0800, Mar. 13	9.9×10^{-6}
Mesquite, Nev	0520, Mar. 12	0900, Mar. 13	1.4×10^{-3}
Nellis, Nev	0520, Mar. 12	0920, Mar. 13	1.7×10^{-6}
Pioche, Nev	0540, Mar. 12	0925, Mar. 13	7.5×10^{-3}
St. George, Utah	0545, Mar. 12	0930, Mar. 13	1.2×10^{-3}
Tonopah, Nev	0545, Mar. 12	0720, Mar. 13	1.2×10^{-5}
Lund, Nev	0520, Mar. 12	1620, Mar. 12	2.0×10^{-4}

SHOT: BEE

Location	From—	To—	Activity uc/m³
Alamo, Nev	0445, Mar. 22	0900, Mar. 23	5.6×10^{-4}
Beaver, Utah	0505, Mar. 22	0905, Mar. 23	1.7×10^{-4}
Caliente, Nev	0445, Mar. 22	0920, Mar. 23	4.5×10^{-4}
Cedar City, Utah	0505, Mar. 22	0905, Mar. 23	9.6×10^{-5}
Currant, Nev	0515, Mar. 22	1015, Mar. 23	2.0×10^{-6}
Ely, Nev	0505, Mar. 22	0900, Mar. 23	1.4×10^{-5}
Glendale, Nev	0515, Mar. 22	1000, Mar. 23	6.5×10^{-4}
Indian Springs, Nev	0515, Mar. 22	0700, Mar. 23	2.7×10^{-6}
Las Vegas, Nev	0505, Mar. 22	1440, Mar. 23	7.7×10^{-4}
Lincoln Mine, Nev	0505, Mar. 22	0905, Mar. 23	2.2×10^{-5}
Lund, Nev	0505 Mar. 22	1015 Mar. 23	4.2×10^{-4}
Mercury, Nev	0455 Mar. 22	0725, Mar. 23	3.4×10^{-6}
Mesquite, Nev	0505, Mar. 22	0820, Mar. 23	2.0×10^{-4}
Nellis, Nev	0505, Mar. 22	1705, Mar. 22	3.5×10^{-3}
Pioche, Nev	0520, Mar. 22	0905, Mar. 23	5.2×10^{-5}
St. George, Utah	0545, Mar. 22	1010, Mar. 23	4.1×10^{-4}
Tonopah, Nev	0855, Mar. 22	2200, Mar. 22	4.2×10^{-6}

TABLE 5.—*Airborne radioactivity concentrations*—Continued

SHOT: ESS

Location	Sampling period		Activity uc/m³
	From—	To—	
Alamo, Nev	1230, Mar. 23	0600, Mar. 25	1.3×10^{-6}
Beatty, Nev	0615, Mar. 23	1200, Mar. 28	5.8×10^{-6}
Beaver, Utah	1230, Mar. 23	2100, Mar. 24	1.2×10^{-5}
Caliente, Nev	1230, Mar. 23	0610, Mar. 25	4.3×10^{-6}
Cedar City, Utah	1000, Mar. 23	0800, Mar. 25	5.8×10^{-6}
Currant, Nev	1230, Mar. 23	0630, Mar. 25	1.9×10^{-6}
Ely, Nev	1000, Mar. 23	0545, Mar. 25	3.6×10^{-6}
Eureka, Nev	1230, Mar. 23	0610, Mar. 25	2.0×10^{-6}
Glendale, Nev	1300, Mar. 23	0630, Mar. 25	2.0×10^{-5}
Indian Springs, Nev	1330, Mar. 23	1430, Mar. 24	6.5×10^{-4}
Las Vegas, Nev	1440, Mar. 23	0600, Mar. 25	2.4×10^{-6}
Lincoln Mine, Nev	1230, Mar. 23	0600, Mar. 25	2.7×10^{-6}
Lund, Nev	1230, Mar. 23	0730, Mar. 25	2.0×10^{-6}
Mercury, Nev	1215, Mar. 23	0930, Mar. 25	4.0×10^{-4}
Mesquite, Nev	1400, Mar. 23	0700, Mar. 25	4.5×10^{-5}
Nellis, Nev	1800, Mar. 23	0600, Mar. 26	2.4×10^{-5}
Pioche, Nev	1255, Mar. 23	0715, Mar. 25	1.7×10^{-6}
St. George, Utah	1010, Mar. 23	0800, Mar. 25	2.2×10^{-5}
Tonopah, Nev	2015, Mar. 23	2015, Mar. 25	3.4×10^{-6}

SHOT: APPLE

Location	From—	To—	Activity uc/m³
Alamo, Nev	0455, Mar. 29	0855, Mar. 30	4.0×10^{-3}
Beaver, Utah	1600, Mar. 29	0900, Mar. 30	4.2×10^{-4}
Caliente, Nev	0430, Mar. 29	0300, Mar. 30	2.7×10^{-3}
Cedar City, Utah	0455, Mar. 29	0930, Mar. 30	9.9×10^{-5}
Currant, Nev	0455, Mar. 29	2300, Mar. 29	4.1×10^{-5}
Ely, Nev	0455, Mar. 29	0645, Mar. 30	4.1×10^{-5}
Eureka, Nev	0430, Mar. 29	0855, Mar. 30	5.9×10^{-6}
Glendale, Nev	0500, Mar. 29	0900, Mar. 30	2.9×10^{-5}
Indian Springs, Nev	450, Mar. 29	0700, Mar. 30	1.3×10^{-4}
Las Vegas, Nev	0455, Mar. 29	1500, Mar. 30	8.6×10^{-5}
Lincoln Mine, Nev	0455, Mar. 29	0855, Mar. 30	3.7×10^{-6}
Lund, Nev	0455, Mar. 29	1030, Mar. 30	1.6×10^{-5}
Mercury, Nev	0455, Mar. 29	0920, Mar. 30	1.1×10^{-5}
Mesquite, Nev	0555, Mar. 29	0855, Mar. 30	4.3×10^{-5}
Nellis, Nev	0500, Mar. 29	1300, Mar. 30	5.4×10^{-5}
Pioche, Nev	0515, Mar. 29	0650, Mar. 30	7.3×10^{-3}
St. George, Utah	0525, Mar. 29	0900, Mar. 30	2.1×10^{-6}
Tonopah, Nev	0500, Mar. 29	0830, Mar. 30	8.8×10^{-5}

SHOT: HA

Location	From—	To—	Activity uc/m³
Alamo, Nev	0950, Apr. 6	1015, Apr. 7	1.4×10^{-4}
Beaver, Utah	1000, Apr. 6	1200, Apr. 7	1.7×10^{-5}
Caliente, Nev	0955, Apr. 6	1355, Apr. 7	5.4×10^{-5}
Cedar City, Utah	1000, Apr. 6	1200, Apr. 7	7.7×10^{-6}
Ely, Nev	1000, Apr. 6	1340, Apr. 7	5.4×10^{-5}
Eureka, Nev	0945, Apr. 6	1150, Apr. 7	4.4×10^{-6}
Glendale, Nev	1000, Apr. 6	1700, Apr. 7	1.6×10^{-6}
Indian Springs, Nev	1000, Apr. 6	0700, Apr. 7	1.4×10^{-5}
Las Vegas, Nev	1200, Apr. 6	0900, Apr. 7	1.3×10^{-5}
Lincoln Mine, Nev	1000, Apr. 6	0600, Apr. 7	1.4×10^{-5}
Lund, Nev	1000, Apr. 6	1240, Apr. 7	8.0×10^{-6}
Mercury, Nev	0900, Apr. 6	1400, Apr. 7	3.9×10^{-6}
Mesquite, Nev	1000, Apr. 6	1200, Apr. 7	1.5×10^{-5}
Nellis, Nev	1000, Apr. 6	1800, Apr. 6	10^{-6}
Pioche, Nev	1024, Apr. 6	1415, Apr. 7	1.1×10^{-6}
St. George, Utah	1040, Apr. 6	1100, Apr. 7	1.1×10^{-5}
Tonopah, Nev	1200, Apr. 6	0900, Apr. 7	9.2×10^{-6}

TABLE 5.—*Airborne radioactivity concentrations*—Continued

SHOT: POST

Location	Sampling period		Activity uc/m³
	From—	To—	
Alamo, Nev	0430, Apr. 9	0830, Apr. 10	4.8 x 10^{-3}
Beaver, Utah	0430, Apr. 9	0800, Apr. 10	7.7 x 10^{-4}
Caliente, Nev	0430, Apr. 9	0845, Apr. 10	1.8 x 10^{-3}
Cedar City, Utah	0430, Apr. 9	0830, Apr. 10	3.9 x 10^{-6}
Ely, Nev	0430, Apr. 9	0800, Apr. 10	1.3 x 10^{-3}
Eureka, Nev	0420, Apr. 9	0840, Apr. 10	6.5 x 10^{-6}
Glendale, Nev	0430, Apr, 9	1430, Apr. 10	3.0 x 10^{-3}
Indian Springs, Nev	0430, Apr. 9	2200, Apr. 9	9.0 x 10^{-4}
Las Vegas, Nev	1500, Apr. 9	0800, Apr. 10	5.8 x 10^{-3}
Lincoln Mine, Nev	0530, Apr. 9	0830, Apr. 10	2.7 x 10^{-3}
Lund, Nev	0450, Apr. 9	0830, Apr. 10	1.8 x 10^{-3}
Mercury, Nev	0425, Apr. 9	1150, Apr. 10	2.5 x 10^{-4}
Mesquite, Nev	0430, Apr. 9	0830, Apr. 10	5.5 x 10^{-6}
Nellis, Nev	0430, Apr. 9	0830, Apr. 10	1.0 x 10^{-3}
Pioche, Nev	0500, Apr. 9	0837, Arp. 10	1.1 x 10^{-3}
St. George, Utah	0520, Apr. 9	0830, Apr. 10	8.5 x 10^{-6}
Tonopah, Nev	0800, Apr. 9	0900, Apr. 10	3.6 x 10^{-6}

SHOT: MET

Location	From—	To—	Activity uc/m³
Alamo, Nev	1105, Apr. 15	1115, Apr. 16	6.7 x 10^{-4}
Beaver, Utah	1115, Apr. 15	1205, Apr. 16	6.1 x 10^{-3}
Caliente, Nev	1200, Apr. 15	1103, Apr. 16	5.0 x 10^{-3}
Cedar City, Utah	1115, Apr. 15	1145, Apr. 16	7.6 x 10^{-4}
Ely, Nev	1115, Apr. 15	2315, Apr. 15	4.8 x 10^{-6}
Eureka, Nev	1115, Apr. 15	0730, Apr. 16	4.0 x 10^{-6}
Glendale, Nev	1120, Apr. 15	1215, Apr. 16	1.6 x 10^{-5}
Indian Springs, Nev	1615, Apr. 15	1315, Apr. 16	4.2 x 10^{-4}
Las Vegas, Nev	1130, Apr. 15	1100, Apr. 16	1.6 x 10^{-5}
Lincoln Mine, Nev	1115, Apr. 15	1115, Apr. 16	5.8 x 10^{-6}
Lund, Nev	1115, Apr. 15	1115, Apr. 16	8.3 x 10^{-6}
Mercury, Nev	1110, Apr. 15	1115, Apr. 16	2.6 x 10^{-5}
Mesquite, Nev	1115, Apr. 15	1515, Apr. 16	5.2 x 10^{-6}
Nellis, Nev	1115, Apr. 15	1115, Apr. 16	1.3 x 10^{-5}
Pioche, Nev	1135, Apr. 15	1115, Apr. 16	2.7 x 10^{-3}
St. George, Utah	1145, Apr. 15	1115, Apr. 16	4.2 x 10^{-6}
Tonopah, Nev	1320, Apr. 15	1000, Apr. 16	9.0 x 10^{-6}

SHOT: APPLE TWO

Location	From—	To—	Activity uc/m³
Alamo, Nev	0510, May 5	0710, May 6	1.2 x 10^{-4}
Caliente, Nev	0510, May 5	0930, May 6	8.6 x 10^{-6}
Cedar City, Utah	0510, May 5	0910, May 6	1.4 x 10^{-5}
Ely, Nev	0510, May 5	0910, May 6	5.9 x 10^{-2}
Eureka, Nev	0510, May 5	0900, May 6	2.4 x 10^{-3}
Glendale, Nev	0510, May 5	0910, May 6	4.1 x 10^{-6}
Indian Springs, Nev	0510, May 5	0700, May 6	5.7 x 10^{-4}
Lincoln Mine, Nev	0510, May 5	0910, May 6	1.8 x 10^{-4}
Lund, Nev	0510, May 5	1210, May 6	1.1 x 10^{-3}
Mercury, Nev	0540, May 5	1220, May 6	1.0 x 10^{-5}
Pioche, Nev	0535, May 5	1015, May 6	2.5 x 10^{-6}
St. George, Utah	1800, May 5	1045, May 6	8.7 x 10^{-6}
Tonopah, Nev	0540, May 5	0750, May 6	3.6 x 10^{-6}

SHOT: ZUCCHINI

Location	From—	To—	Activity uc/m³
Alamo, Nev	0500, May 15	0900, May 16	1.5 x 10^{-5}
Caliente, Nev	0530, May 15	0945, May 16	6.7 x 10^{-6}
Cedar City, Utah	0500, May 15	0910, May 16	7.8 x 10^{-6}
Indian Springs, Nev	0500, May 15	0700, May 16	6.6 x 10^{-4}
Las Vegas, Nev	0500, May 15	1000, May 16	1.1 x 10^{-3}
Lincoln Mine, Nev	0500, May 15	0715, May 15	8.5 x 10^{-6}
Mercury, Nev	0510, May 15	0900, May 16	1.4 x 10^{-5}
Mesquite, Nev	0555, May 15	0830, May 16	4.2 x 10^{-3}
Nellis, Nev	0500, May 15	0800, May 16	1.5 x 10^{-3}
Pioche, Nev	0510, May 15	1105, May 16	1.3 x 10^{-6}
St. George, Utah	0645, May 15	1030, May 16	4.3 x 10^{-3}

APPENDIX

PERSONNEL

A total of 66 Public Health Service men were assigned to this operation for various periods of time. PHS personnel were composed of two categories, regular PHS personnel, and Reserve personnel who were called to active duty for the purpose of assignment to this operation.

The regular PHS personnel and their normal affiliation are as follows:

Anderson, E. C., Assistant Chief, radiological health program
Bevis, Herbert A., radiological health program, Washington, D. C.
Brewer, Lial W., occupational health field station, Salt Lake City
Butrico, Frank A., DHEW, region 2, New York, N. Y.
Carter, Melvin W., PHS, offsite program, Nevada test site
Coleman, Richard D., radiological health program, Salt Lake City
Ernsberger, Edward L., PHS, Rockville, Md.
Fooks, Jack H., DHEW, region 8, Denver, Colo.
Hagee, G. Richard, Robert A. Taft Sanitary Engineering Center, Cincinnati
Henderson, Paul C., DHEW, region 3, Washington, D. C.
Holaday, Duncan A., occupational health field station, Salt Lake City
Ingraham, Samuel C., M. D., National Cancer Institute, NIH, Bethesda, Md.
Kusnetz, Howard L., occupational health field station, Salt Lake City
Longaker, Ralph K.,DHEW, DESE, Washington, D. C.
Macomber, Ronald G., DHEW, region 2, New York, N. Y.
Mills William A., radiological health program, Washington, D. C.
Minken, Joseph L., CDC, Mount Vernon, N. Y.
Placak, Oliver R., officer in charge, PHS offsite program, Nevada test site
Powell, Clinton C., M. D., National Cancer Institute, NIH, Bethesda, Md.
Rechen, Henry J. L., radiological health program, Washington, D. C.
Schreeder, William B. DHEW, region 9, San Francisco, Calif.
Seal, Morgan S., radiological health program, Washington, D. C.
Soneda, Shinji, Robert A. Taft Sanitary Engineering Center, Cincinnati
Stangler, Marlow, Robert A. Taft Sanitary Engineering Center, Cincinnati
Terrill, James G., Jr., Chief radiological health program, Washington, D. C.

The Reserve personnel who were called to active duty, with the designation of their normal affiliation, are listed below:

Alabama:
  Habel, John C., Jefferson County Health Department, Birmingham
  Thomas, Fred W., USTVA, Wilson Dam
Arkansas: Wilson, Edward F., Arkansas State Board of Health, Little Rock
California:
  Ausseresses, W. M., Southern Pacific Railroad, San Francisco
  Brewer, Robert, State department of health, San Bernardino
  Stone, Ralph N., consulting engineer (civil), Los Angeles
  Vaden, John D., Los Angeles County Health Department, Los Angeles
Colorado:
  Newman, Edison E., State Health Department, Denver
  VanNattan, W. R., State Health Department, Denver
Connecticut:
  Bertran, Albert E., State Health Department, Hartford
  Herlihy, James F., City Health Department, Hartford
  Holt, John A., City Health Department, Hartford
Florida: Greenley, John W., Dade County Health Department, Miami
Georgia: Fetz, Richard H., State Health Department, Atlanta
Hawaii: Woo, Francis H., Department of Health, Hilo
Idaho:
  Cotton, Charles E., State Health Department, Boise
  Despain, Carroll E., City-County Health Department, Boise
Illinois:
  Bullock, Harrison E., State Health Department, Carbondale
  Kaufmann, Oliver W., University of Illinois, Urbana
Indiana: Wraight, Frank D., State Health Department, Indianapolis
Kansas: Rucker, Vernon L., Santa Fe Railroad, Topeka
New Jersey:
  Baker, Walter C., New Jersey Neuropsychiatric Institute, Princeton
  Berry, Clyde M., Esso Standard Oil Co., Linden

New Mexico: Jensen, Carl R., State Health Department, Santa Fe
New York: Marchese, Anthony S., State Highway Department, Poughkeepsie
North Carolina:
- Ameen, Joseph S., State Health Department, Raleigh
- Long, William N., Gaston County Health Department, Gastonia
- Seagle, Edgar F., State Health Department, Raleigh
- Sharpe, Thomas J., District Health Department, Hickory
- Williams, Giles M., State Department of Agriculture, Raleigh

North Dakota: Olson, Otmar O., District Health Department, Williston
Oklahoma:
- Harris, Carroll F., Oklahoma A. and M., Stillwater
- Pummill, Lloyd F., State Health Department, Oklahoma City

Oregon: Bower, William F., State Health Department, Portland
Tennessee:
- Brockett, Thomas W., Oak Ridge National Laboratory
- Davidson, Charles M., USTVA, Chattanooga
- Harless, Bennett L., Oak Ridge National Laboratory

Texas: Ledbetter, Joe O., State Highway Department, Weatherford
Vermont: Gilbert, Wilfred C., State Highway Department, Montpelier
Washington:
- Gregg, George O., State Department of Health, Chehalis
- Ruppert, Edwin L., State Department of Health, Seattle

Abbreviations and Nomenclature

CP—Control point, located in Yucca Pass between Frenchman and Yucca Flats.
GZ—Ground zero, the point above which a device is detonated.
hr—Hour.
mr—milliroentgen.
r—roentgen.
D-day—The day of a particular detonation.
H—The hour of exact time of a particular detonation.
U. S.—Refers to a specific highway.
uc—microcuries.
m^3—Cubic meters.
N—North.
E—East.
S—South.
W—West.
Mi.—Miles.
NTS—Nevada test site.
Times—Pacific standard time through 2 a. m. April 24, 1955; thereafter, Pacific daylight standard time.
EBD—Effective biological dose as defined in the DBM criteria.
AEC—Atomic Energy Commission.
PHS—Public Health Service.
CAA—Civil Aeronautics Administration.
ml—Milliliter.
Co^{60}—An isotope of cobalt having the mass number 60.
MSA—Mine safety appliance.
Sr^{90}—An isotope of strontium having the mass number 90.
Y^{90}—An isotope of yttrium having the mass number 90.

The following system of terminology is used when presenting data concerning airway closure patterns, cloud tracking, and low-level terrain surveys:

1. All elevations are given in terms of mean sea level unless otherwise stated.
2. All bearings are given in terms of true bearings unless otherwise stated.
3. In giving locations, the Georef coordinate system has been used for simplicity. In this system, a group of 4 letters and 4 numbers locates any given point. In the area of concern to this report, the first two letters, EJ, are common to all locations and are omitted for the sake of brevity. Of the second group of two letters, the first letter denotes longitude and the second latitude, according to the following table:

Georef letter	Longitude	Georef letter	Latitude
A	120°00′W.		
B	119°00′		
C	118°00′	C	32°00′N.
D	117°00′	D	33°00′
E	116°00′	E	34°00′
F	115°00′	F	35°00′
G	114°00′	G	36°00′
H	113°00′	H	37°00′
J	112°00′	J	38°00′
K	111°00′	K	39°00′
L	110°00′	L	40°00′
M	109°00′	M	41°00′
N	108°00′	N	42°00′
P	107°00′	P	43°00′
Q	106°00′		

Similarly, the 2 groups of 2 members each denote, respectively, minutes of longitude and minutes of latitude within the 1° quadrangle specified by the letter group. To provide an example, the coordinates of Las Vegas are EG 5120.

The identification of the 15° quadrangle (EJ) is omitted for the reason previously stated.

EG identifies the 1° quadrangle.

51 identifies the Georef minute of longitude.

20 identifies the Georef minute of latitude.

Radiation Exposures Received on Populated Atolls as a Result of Operation Redwing

During Operation Redwing 4 gamma intensity readings daily were taken at populated off-site atolls utilizing a radiac meter AN/PDR-27F, calibrated against a standard consisting of 7 micrograms of radium. Following each test, hourly readings were taken for an interval of time dependent upon fallout forecasts, wind conditions at and following test time, cloud tracking, and readings obtained at the atolls. The attached tables and charts show the weighted daily averages of these readings for the atolls at which stations were maintained.

An estimated cumulative exposure of the populations of these atolls resulting from Operation Redwing has been computed based on these meter readings. Net readings (above preoperation background) have been utilized. Where a residual radiation remained at the time the stations were inactivated, the 70-year exposure due to this residual was computed based on the equation $I_1T_1^{-k}=I_2T_2^{-k}$. Based on available decay data, k=1.2 was utilized. It will be noted that the last day's reading at Ujelang was 1.5 mr/hr. This was due to the test of July 21. The complete record shows that fallout had stopped and radiation intensities were decreasing at the time the station was inactivated. A reduction factor to determine effective biological dose was not utilized as conditions under which the natives live are not believed to warrant the commonly accepted reduction factor. Computations involved are attached. On this basis, 70-year external gamma doses resulting from Operation Redwing are as follows:

Ujelang Atoll: 560 mr.
Utirik Atoll: 53 mr.
Wotho Atoll: 616 mr.
Rongerick Atoll: 853 mr.

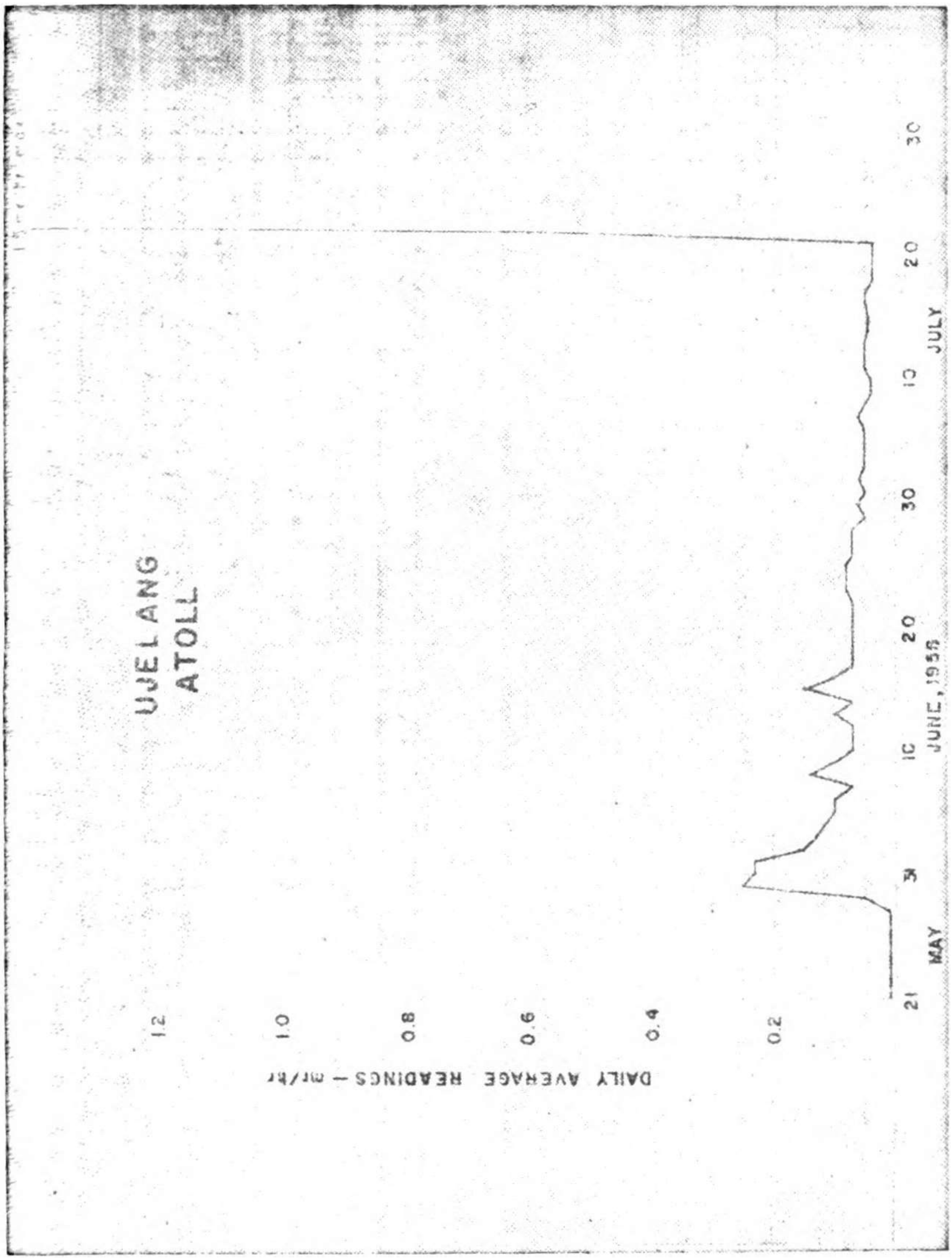
Also attached is a plot showing AN/PDR-27F readings at JTF-7 Headquarters, Parry Island, during the period July 21 to July 23, 1956. On the basis of these figures, effective external gamma doses to various periods of time have been computed as follows:

H+5 days: 3.45 R.
H+15 days: 5.7 R.
H+1 year: 7.95 R.
Infinity dose: 12.45 R.

Computations are attached.

Daily average readings

Date	Ujelang	Utirik	Wotho	Rongerik	Date	Ujelang	Utirik	Wotho	Rongerik
Apr. 26	0.01	0.02	0.01	0.1	June 26	.07	.02	.3	.5
May 29	.05	.03	.2	.15	June 27	.07	.02	.25	.1
May 30	.25	.03	4.5	.30	June 28	.07	.06	.25	.1
May 31	.26	.26	.26	.26	June 29	.05	.15	.23	.1
June 1	.23	.03	1.0	3.0	June 30	.06	.15	.23	.1
June 2	.15	.03	.85	3.0	July 1	.05	.15	.21	.1
June 3	.13	.02	.75	3.0	July 2	.06	.11	.21	.1
June 4	--------	.02	--------	2.0	July 3	.05	.11	.19	.1
June 5	.1	.02	.5	2.0	July 4	.05	.10	.18	.1
June 6	.1	.02	.4	2.0	July 5	.05	.10	.18	.1
June 7	.07	.02	.3	2.0	July 6	.05	.08	.18	.1
June 9	--------	--------	--------	1.5	July 7	.06	.08	.15	.1
June 10	--------	--------	--------	1.0	July 8	.05	.07	.14	.1
June 11	--------	--------	--------	1.0	July 9	.04	.07	.14	.1
June 12	.07	.02	.2	1.0	July 10	.04	.05	.11	.1
June 13	.1	.02	.18	1.0	July 11	.05	.06	.11	.1
June 14	.07	.02	.48	2.0	July 12	.05	.05	.12	.1
June 15	.15	.02	.90	1.5	July 13	.05	.05	.10	.1
June 16	.1	.04	.8	1.0	July 14	.045	.04	.10	.1
June 17	.07	.05	.7	1.0	July 15	.045	.045	.10	.1
June 18	.07	.04	.6	1.0	July 16	.05	.05	.09	.1
June 19	.07	.04	.7	1.0	July 17	.05	.04	.08	.1
June 20	.07	.03	.6	1.0	July 18	.04	.05	.08	.1
June 21	.07	.02	.5	1.0	July 19	.04	.04	.08	.1
June 22	.07	.02	.5	1.0	July 20	.04	.04	.08	.1
June 23	.08	.03	.4	1.0	July 21	.04	.04	.08	.1
June 24	.08	.02	.4	.75	July 22	.6	.04	.08	.1
June 25	.08	.03	.3	.5	July 23	1.5	--------	--------	.1

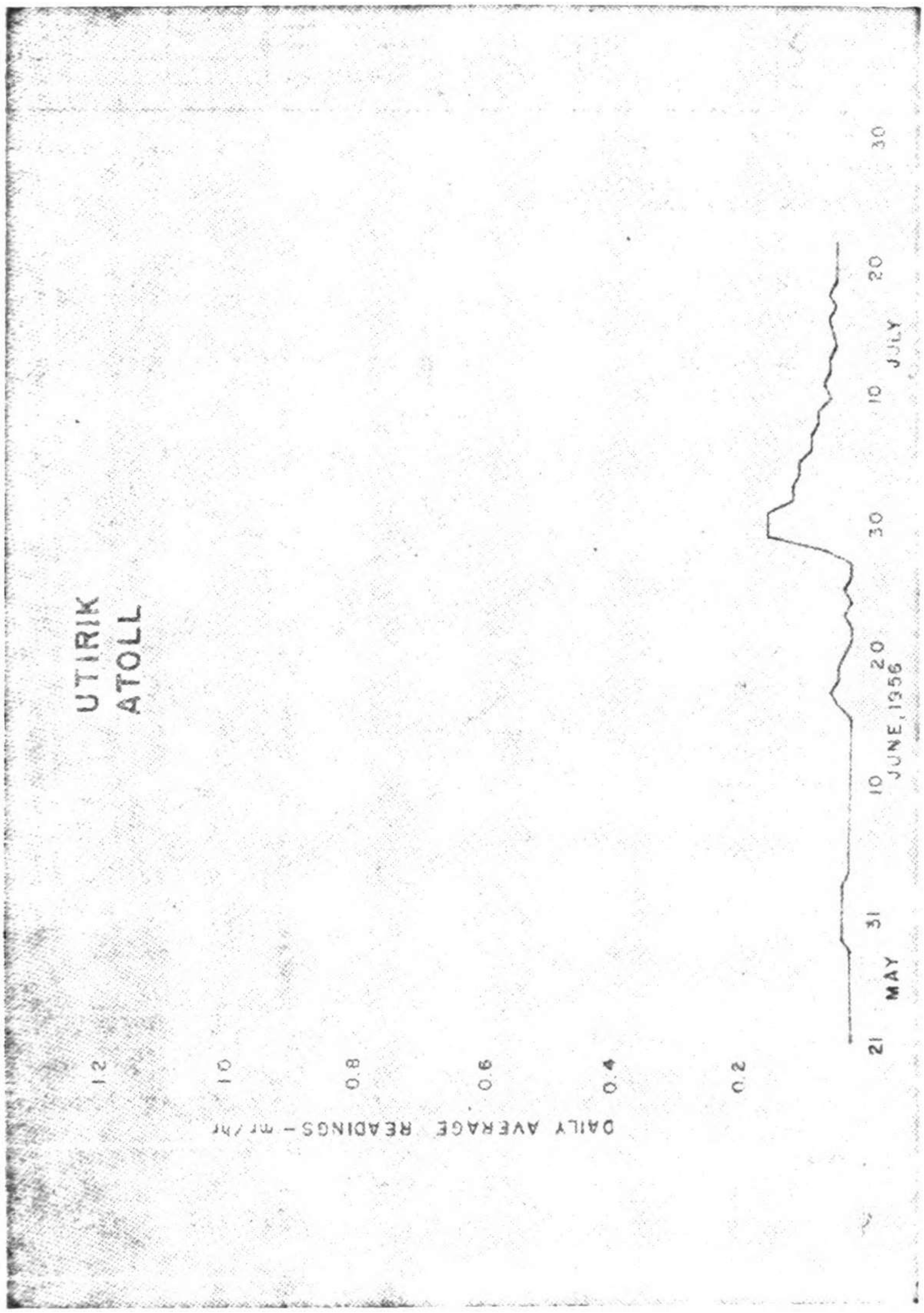

UJELANG
ATOLL
DAILY AVERAGE READINGS — mr/hr
1.2
1.0
0.8
0.6
0.4
0.2
21
31
10
20
30
10
20
30
MAY
JUNE
JULY

Cumulative exposure computations—Ujelang

Rate mr./hr.	Days	Hours	Dose mr.	Rate mr./hr.	Days	Hours	Dose mr.
0.04	13	312	12.48	0.07	3	72	5.04
0.24	1	24	5.76	0.13	1	24	3.12
0.23	1	24	5.52	0.10	3	72	7.20
0.22	1	24	5.28	0.05	4	96	4.80
0.14	2	48	6.72	0.03	6	144	4.32
0.12	1	24	2.88	0.035	2	48	1.68
0.11	1	24	2.64	1.5	1	24	36.00
0.09	4	96	8.64				
0.06	12	288	17.28	Total			[2] 129.36

TEWA H=210600 M
240000 M=H+66 hours=2.75 days
70 year dose after this time=approx. 430 mr. assuming $I_2T_1^{-1.2}=I_1T_2^{-1.2}$.[2]
Total 70 year dose=130+430=560 mr.

[1] Rate above preoperation background of 0.01 mr./hr.
[2] Through July 23.

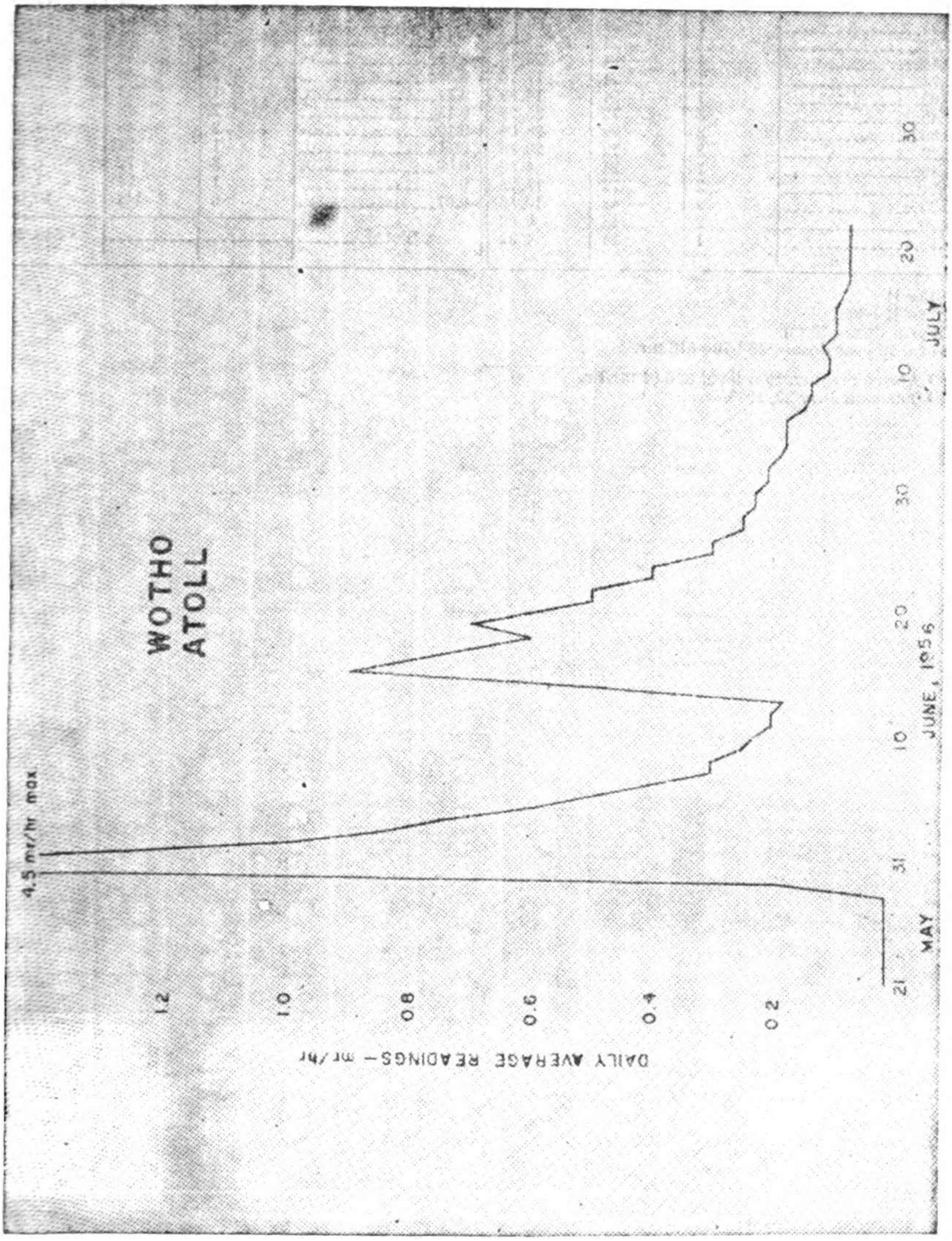

UTIRIK
ATOLL
DAILY AVERAGE READINGS – mr/hr
1.2
1.0
0.8
0.6
0.4
0.2
21
MAY
31
10
JUNE, 1956
20
30
10
JULY
20
30

Cumulative exposure computation—Utirik

Rate [1] mr./hr.	Days	Hours	Dose mr.	Rate [1] mr./hr.	Days	Hours	Dose mr.
0.01	8	192	1.92	0.09	2	48	4.32
0.02	9	216	4.32	0.08	2	48	3.84
0.025	1	24	0.60	0.06	2	48	2.88
0.03	6	144	4.32	0.05	2	48	2.40
0.04	2	48	1.92				
0.13	3	72	9.36	Total			35.88

[1] Rate above preoperation background of 00.2 mr./hr.

Assume D=June 27
70-year dose from July 23=approx. 17 mr.
Total 70-year dose=36+17=53 mr.

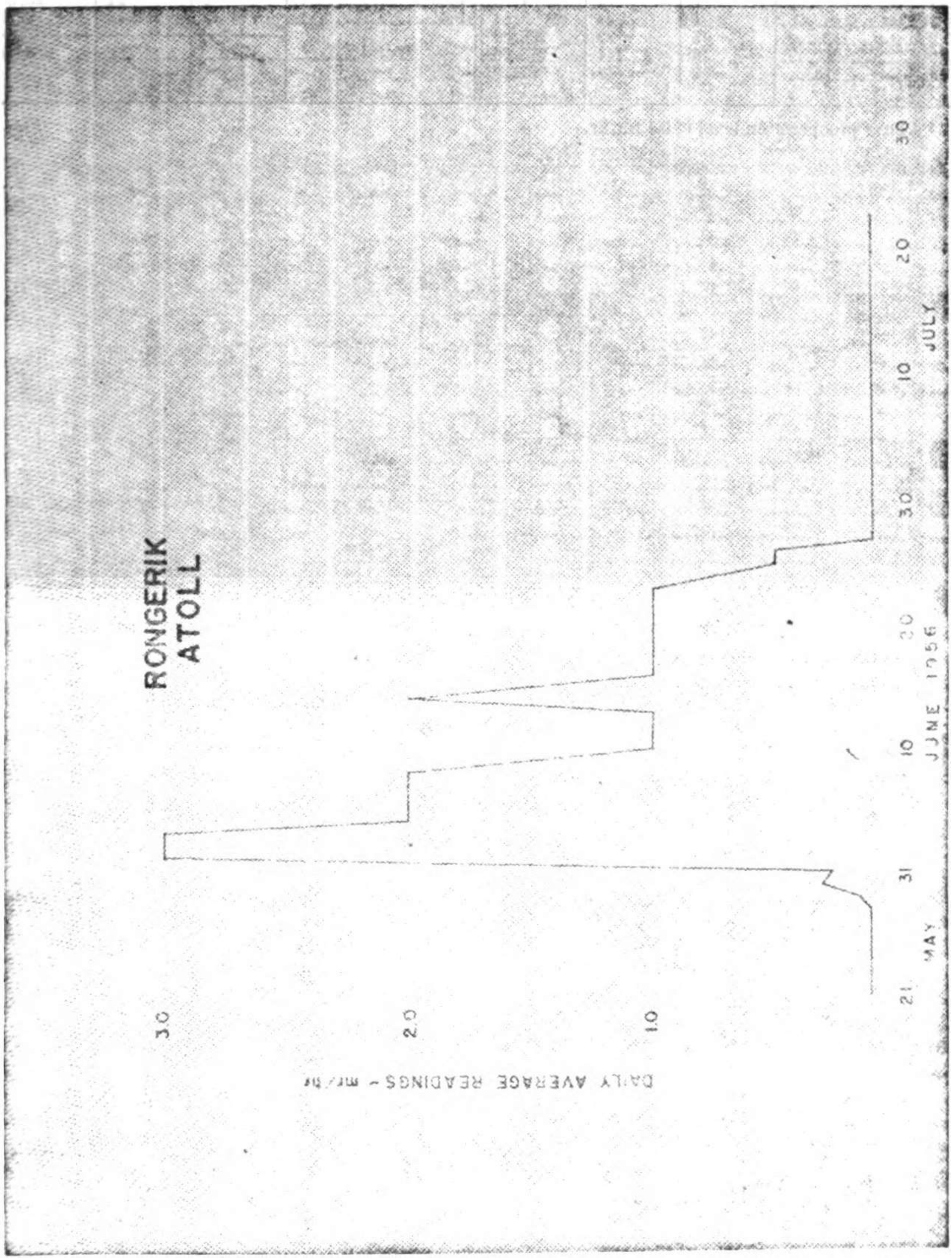

WOTHO
ATOLL
4.5 mr/hr max.
DAILY AVERAGE READINGS — mr/hr
1.2
1.0
0.8
0.6
0.4
0.2
21
MAY
31
10
JUNE, 1956
20
30
10
JULY
20
30

Cumulative exposure computation—Wotho

Rate [1] mr/hr.	Days	Hours	Dose mr.	Rate [1] mr/hr.	Days	Hours	Dose mr.
0.01	1	24	0.24	0.17	4	96	16.32
4.5	1	24	108.00	0.47	1	24	11.28
2.75	1	24	66.00	0.89	1	24	21.36
1.0	1	24	24.00	0.79	1	24	18.96
0.84	1	24	20.16	0.69	2	48	33.12
0.74	1	24	17.76	0.59	2	48	28.32
0.62	1	24	14.88	0.14	1	24	3.36
0.49	3	72	35.28	0.13	2	48	6.24
0.39	3	72	28.08	0.10	2	48	4.80
0.29	3	72	20.88	0.11	1	24	2.64
0.19	1	24	4.56	0.09	3	72	6.48
0.24	3	72	17.28	0.08	1	24	1.92
0.22	2	48	10.56	0.07	6	144	10.08
0.20	2	48	9.60				
0.18	1	24	4.32	Total			[2] 546.48

6/13=H
7/23=H+40 d
70 year dose=70 mr
Total 70 year dose=546+70=616 mr.

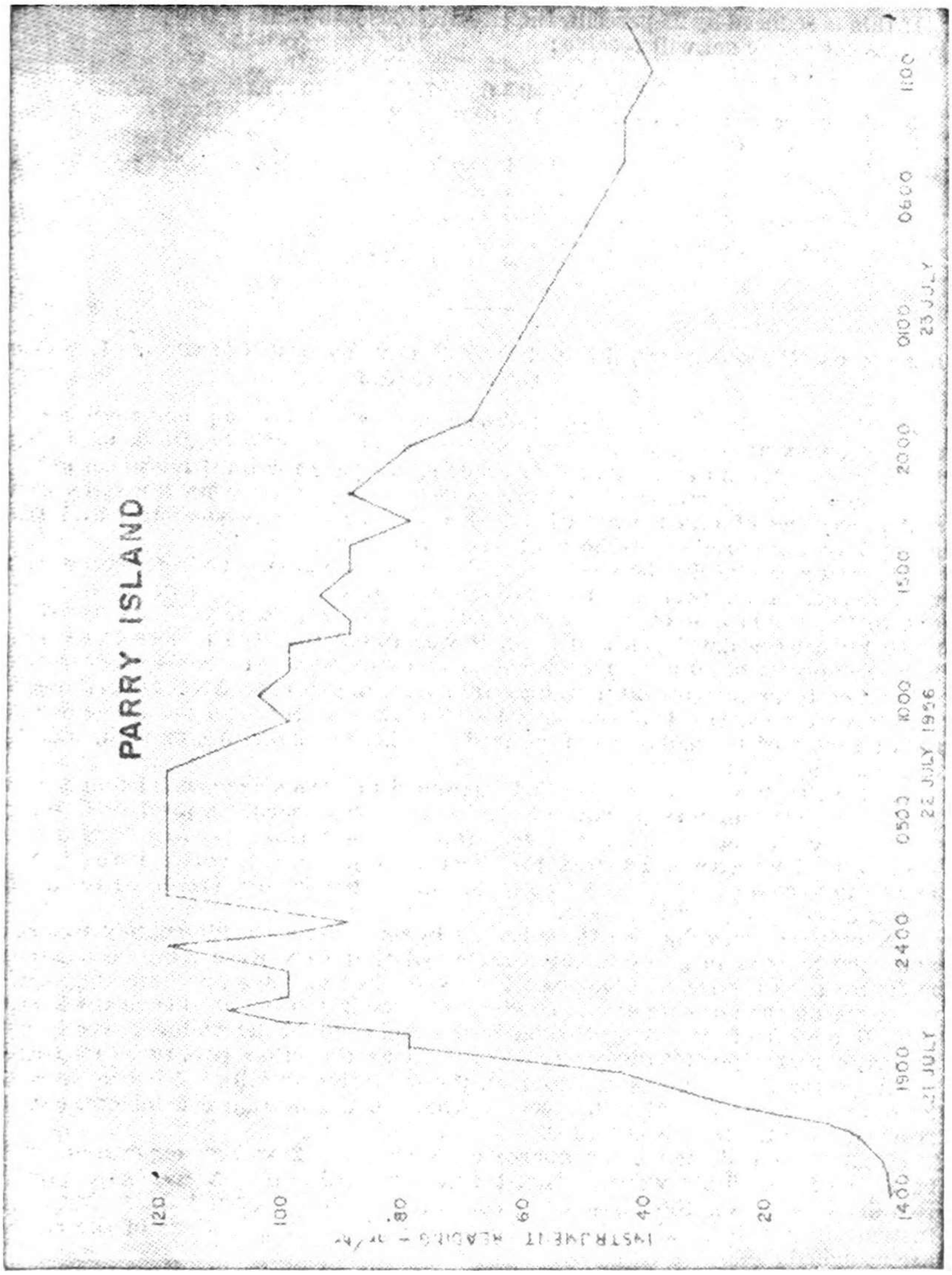
[1] Above preoperation level of 0.01 mr/hr.
[2] Through July 22, 1956.


RONGERIK
ATOLL
3.0
2.0
1.0
DAILY AVERAGE READINGS ~ mr/hr
21
MAY
31
10
JUNE 1956
20
30
10
JULY
20
30

Cumulative exposure computation—Rongerik

Rate [1] mr/hr	Days	Hours	Dose mr.	Rate [1] mr/hr.	Days	Hours	Dose mr.
0.05	1	24	1.20	0.9	12	288	295.20
0.2	1	24	4.80	0.65	1	24	15.60
0.16	1	24	3.84	0.4	2	48	19.20
2.9	3	72	208.80				
1.9	6	144	273.60	Total			853.44
1.4	2	48	67.20				

[1] Above preoperation level of 0.1 mr/hr.


PARRY ISLAND
120
100
80
60
40
20
1400
1900
21 JULY
2400
0500
22 JULY 1956
1000
1500
2000
0100
23 JULY
0600
1100

DOSE CALCULATIONS FOR PARRY ISLAND

Accumulated dose to 220700 M was 0.6R
At that time decay started with the decay constant K=−1.2
Personnel leaving at H+5 days will receive:

16−12+0.6=4.6 R

If this is reduced by 25 percent, the effective dose=3.45 R
Permanent personnel will receive:
For first 15 days:

16−9+0.6=7.6 R

Effective 15 day dose=(0.75) (7.6)=5.7 R
For 15 days to 1 year:

9−4.5=4.5 R

Effective dose=(0.5) (4.5)=2.25 R
Total effective dose to end of 1 year=7.95 R
Infinity dose for permanent personnel:

7.95+4.5=12.45 R

REPORT ON EXPERIMENTAL FILM BADGE STUDY DURING OPERATION REDWING, OCTOBER 1, 1956

During Operation Redwing the Public Health Service group had planned, on an experimental basis, to utilize film badges on the off-site atolls of Utirik, Ujelang, and Wotho as a method of securing a figure for total radiation dosage on these islands. Arrangements were made for the procurement, transportation, and processing of film badges with task group 7.1 radsafe personnel and task group 7.4 nuclear research officer, Lt. W. J. Jameson.

The first group of film badges, enclosed in rigid, transparent plastic containers, were exposed for a period of approximately 50 days. A second group was sent out to the atolls and exposed for a period of approximately 15 days. When these films were developed and read, it was found that the results were much higher (up to 5 to 10 times) than would be expected on the basis of exposures computed from instrument readings taken at the atolls (AN/PDR27F geiger counters were used). On examination of the films, water marks could be clearly seen on most of them. It was theorized that heat or moisture, or both, was the cause of the high readings.

Capt. B. H. Purcell, task group 7.1, arranged to have some special film badges prepared. One lot was prepared by having the film packet dipped in Ceresine wax before sealing in the plastic case (referred to in this report as "film dipped badges"). The second lot was prepared by dipping the entire case in wax after the uncoated film packet was sealed in the pastic case (referred to in this report as "case dipped badges").

Preliminary work done on these badges by exposing them alternately to steam and then placing in a refrigerator indicated that they were more resistant to moisture than the regular badges. It was decided to place approximately 20 of each type on each off-site atoll, bringing in 3 sets from each atoll each week until the reliable life of each type of badge in the field could be determined. (Only half as many film dipped badges were available as the other two types.) Unfortunately, for the purposes of this test, the operation terminat d before it could be completed. It is believed, however, that some tentative conclusions can be reached from the results obtained.

Films were collected after approximately 1 and 2 weeks' exposures. The balance of the films were collected after approximately 3 weeks' exposure. Readings taken on the films were compared with calculated doses based on instrument readings taken during the same periods. Tabulations of the results are attached.

It can be seen that the doses received during the first week are too low to give reliable results on the film badges used, while exposures received during the first 2 weeks are just at the borderline of sensitivity. All film badges appeared to be satisfactory after 1 week, but after 2 weeks the regular badges were showing signs of moisture penetration. After 3 weeks, almost all the regular badges, while none of the film-dipped or case-dipped badges, were watermarked.

Estimating the dose to which the films brought in after 3 weeks were exposed is complicated by the fact that Parry Island had a gamma radiation level of 20 to 30 mr/hr at the time the films reached there. Thus, it has been necessary to estimate exposure received at Eniwetok Atoll prior to development. How-

ever, a study of the results on these badges is believed to indicate a trend. Attached are curves showing the distribution of results for each type of film from each atoll and the results for each type of film from the three atolls combined.

Considering this latter curve, if one considers results within 50 percent of a "true" (in this case, calculated) dose to be satisfactory, it can be seen that 68 percent of the film-dipped badges and 60 percent of the case-dipped badges fall within this range, while only 19 percent of the regular badges meet this criterion. This is admittedly a limited sample, but the results are believed to warrant the following conclusions and recommendations:

1. Climatic conditions at the Pacific Proving Grounds have an adverse effect on ordinary film badges to the extent that they cannot be relied upon to give satisfactory results:

2. If possible, a study should be made to determine the reliable life of wax-coated film badges and possibly other types of dosimeters) under climatic conditions similar to those at Pacific Proving Grounds prior to the next test series. If this is not possible, such a study should be conducted at Pacific Proving Grounds during the next series.

3. For area monitoring of this type, a more sensitive film should be included in the film packet.

Experimental film badges—Ujelang Atoll

Station No.	Date out	Date in	Time exposed, in days	Indicated dose, milliroentgen			Calculated dose, milliroentgen
				Regular	C. D.	F. D.	
7	July 4, 1956	July 10, 1956	7	[1] 50	30	----------	8
18	do	do	7	70	30	30	8
10	do	July 17, 1956	13	[1] 70	0	0	16
11	do	do	13	[1] 90	30	----------	16
1	do	July 26, 1956	23	[1] 210	90	70	143
2	do	do	23	[1] 245	90	----------	143
3	do	do	23	[1] 210	110	70	143
4	do	do	23	[1] 225	110	90	143
5	do	do	23	[1] 350	110	----------	143
6	do	do	23	[1] 170	90	70	143
8	do	do	23	[1] 245	130	----------	143
9	do	do	23	[1] 280	110	----------	143
12	do	do	23	[1] 280	110	90	143
13	do	do	23	[1] 245	90	----------	143
14	do	do	23	[1] 330	110	----------	143
15	do	do	23	[1] 265	90	70	143
16	do	do	23	[1] 225	50	70	143
17	do	do	23	[1] 265	110	110	143

[1] Film watermarked.

Experimental film badges—Utirik Atoll

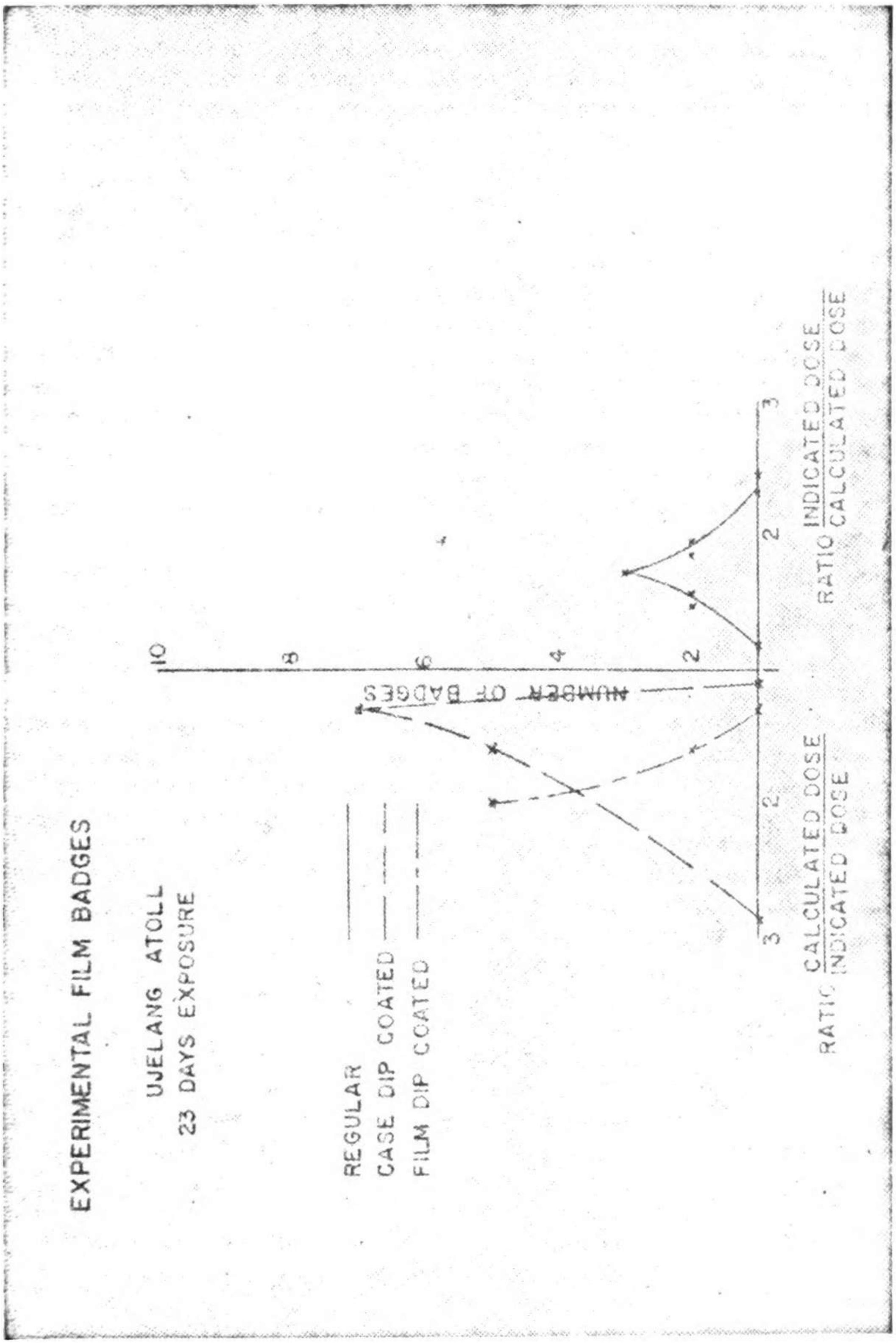
Station No.	Date out	Date in	Time exposed, in days	Indicated dose, milliroentgen			Calculated dose, milliroentgen
				Regular	C. D.	F. D.	
1	July 8, 1956	July 14, 1956	7	70	50	50	9.0
2	do	do	7	70	50	----------	9.0
1	do	July 26, 1957	19	90	70	----------	41.5
3 [2]	do	do	19	[1] 470	425	410	41.5
4 [2]	do	do	19	470	440	----------	41.5
5	do	do	19	110	70	[3] 365	41.5
6	do	do	19	110	70	----------	41.5
7	do	do	19	[1] 130	50	50	41.5
8	do	do	19	[1] 130	70	----------	41.5
9	do	do	19	[1] 130	50	50	41.5
10	do	do	19	[1] 130	70	----------	41.5
11	do	do	19	[1] 130	70	50	41.5
12	do	do	19	[1] 130	70	----------	41.5
13 [2]	do	do	19	[1] 440	440	440	41.5
14	do	do	19	[1] 110	70	----------	41.5
15	do	do	19	[1] 110	70	50	41.5
16	do	do	19	90	70	----------	41.5
17	do	do	19	90	70	----------	41.5

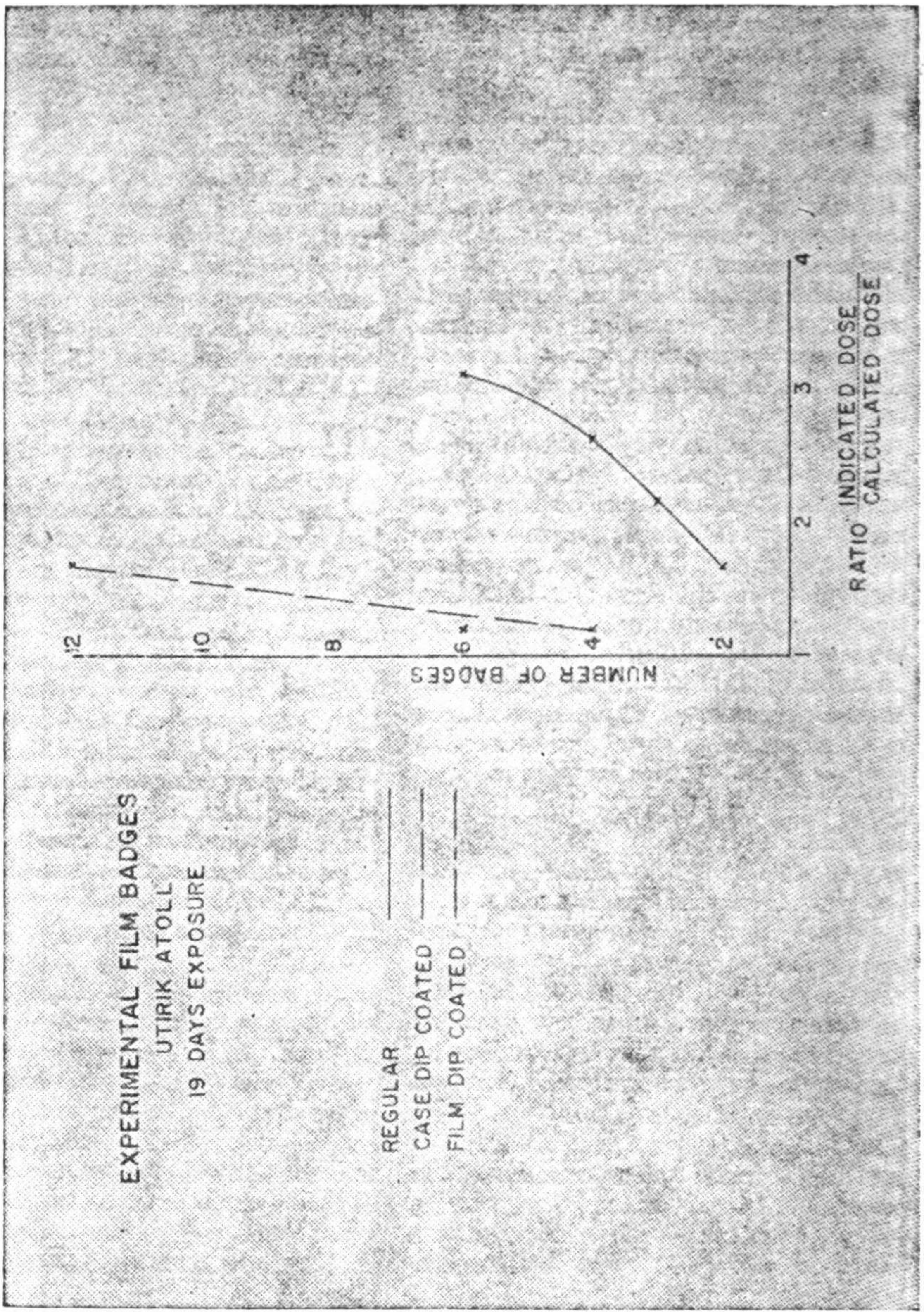
[1] Film watermarked.
[2] Films developed separately from other films exposed during this same period.
[3] Fogging due to unknown cause.

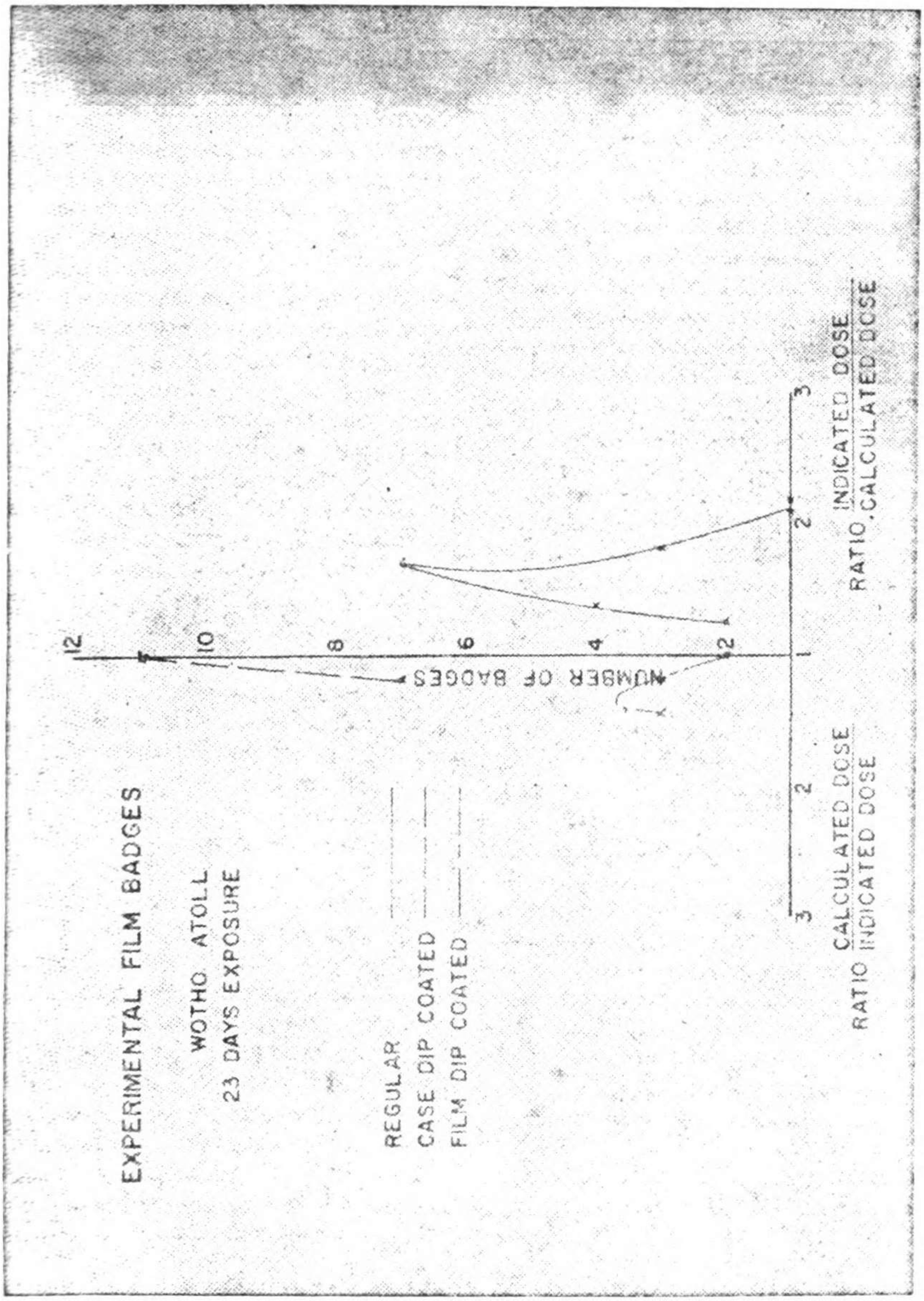
Experimental film badges—Wotho Atoll

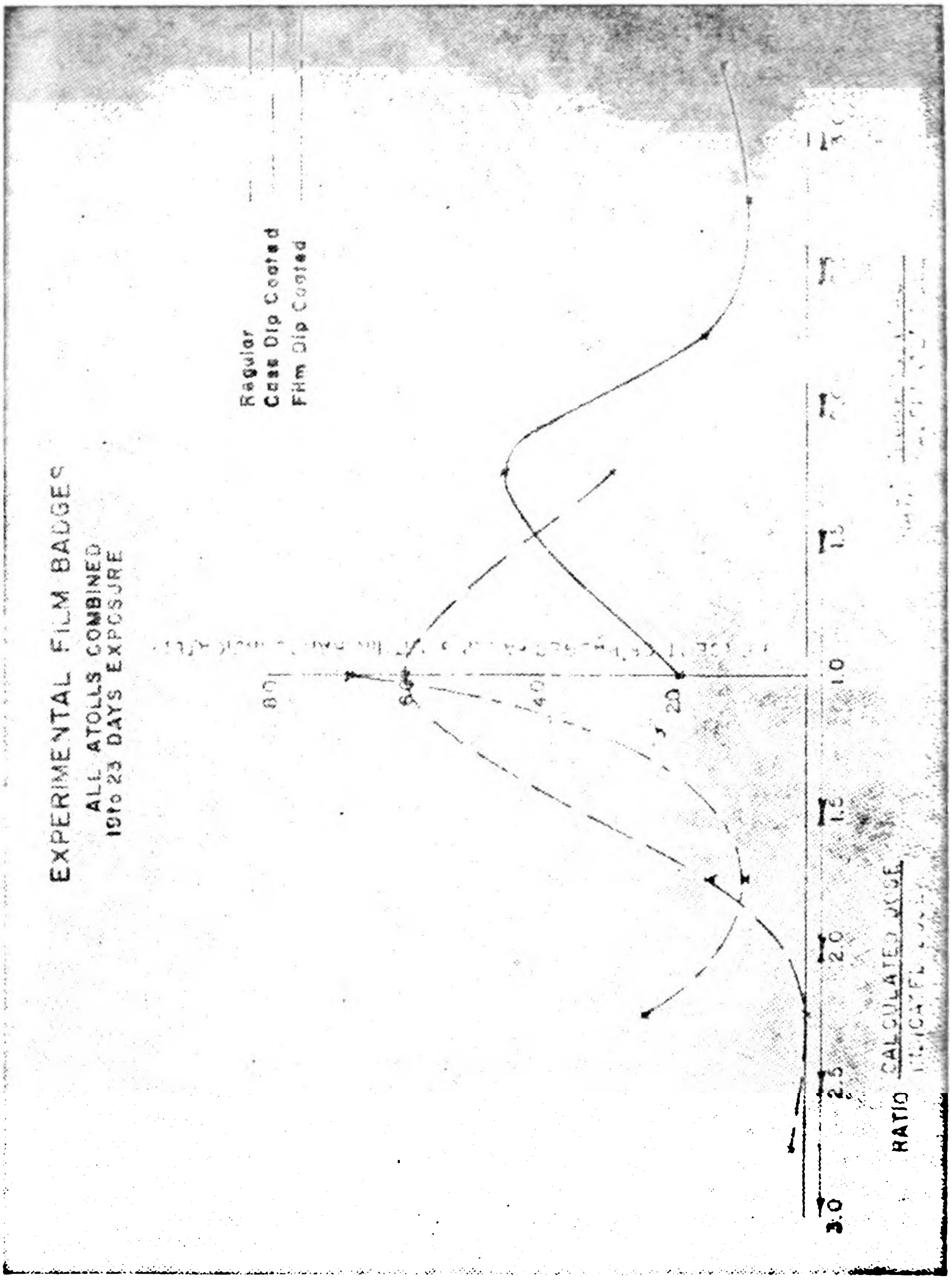
Station No.	Date out	Date in	Time exposed, in days	Indicated dose, mr.			Calculated dose, mr.
				Regular	C. D.	F. D.	
10	July 2, 1956	July 9, 1956	8	30	30	30	33
9	do	July 16, 1956	15	70	30	30	50
1	do	July 24, 1956	23	[1] 160	130	90	130
2	do	do	23	[1] 180	130	90	130
3	do	do	23	[1] 180	130	90	130
4	do	do	23	[1] 180	130	110	130
5	do	do	23	[1] 160	130	110	130
6	do	do	23	[1] 220	130	110	130
7	do	do	23	[1] 220	130	130	130
8	do	do	23	[1] 270	110	130	130
11	do	do	23	[1] 220	130		130
12	do	do	23	[1] 220	110		130
13	do	do	23	[1] 235	130		130
14	do	do	23	[1] 220	130		130
15	do	do	23	[1] 220	110		130
16	do	do	23	[1] 235	110		130
17	do	do	23	[1] 235	110		130
18	do	do	23	[1] 285	110		130
19	do	do	23	[1] 180	130		130
20	do	do	23	[1] 220	110		130

[1] Film watermarked.


EXPERIMENTAL FILM BADGES
UJELANG ATOLL
23 DAYS EXPOSURE
REGULAR
CASE DIP COATED
FILM DIP COATED
NUMBER OF BADGES
10
8
6
4
2
3
2
1
2
3
RATIO CALCULATED DOSE / INDICATED DOSE
RATIO INDICATED DOSE / CALCULATED DOSE


EXPERIMENTAL FILM BADGES
UTIRIK ATOLL
19 DAYS EXPOSURE
REGULAR
CASE DIP COATED
FILM DIP COATED
NUMBER OF BADGES
2
4
6
8
10
12
RATIO INDICATED DOSE / CALCULATED DOSE
2
3
4


EXPERIMENTAL FILM BADGES
WOTHO ATOLL
23 DAYS EXPOSURE
REGULAR
CASE DIP COATED
FILM DIP COATED
NUMBER OF BADGES
12
10
8
6
4
2
1
2
3
2
3
RATIO CALCULATED DOSE / INDICATED DOSE
RATIO INDICATED DOSE / CALCULATED DOSE


EXPERIMENTAL FILM BADGES
ALL ATOLLS COMBINED
19 to 23 DAYS EXPOSURE
Regular
Case Dip Coated
Film Dip Coated
RATIO CALCULATED DOSE
80
60
40
20
1.0
1.5
2.0
2.5
3.0

A Brief Review of the Public Health Service Radiation Surveillance Network Operated by the Public Health Service Under an Agreement With the Division of Biology and Medicine, Atomic Energy Commission, May 22, 1957

For the principal purpose of providing immediately useful environmental radiological health data, the Public Health Service, by an agreement with the Division of Biology and Medicine, AEC, dated April 15, 1956, established a nationwide radiation surveillance network, with a central laboratory service located in Washington, D. C.

Originally established to encompass the period of Operation Redwing conducted by the United States at the Pacific Proving Ground in 1956, the network stations commenced operation in April 1956 and ceased intensive operation on September 28, 1956. Sampling data were received from Hawaii, Alaska, and 28 States. The gratifying cooperation of the State and Territorial departments of health made possible the staffing and operation of 29 field stations on a cooperative basis.

During the period of September 28, 1956, to May 1, 1957, the Public Health Service encouraged and assisted in the continued operation of the field sampling stations. As a result, between 3 and 8 of the stations continued to submit samples, which were processed in the central laboratory.

An extension of the PHS–AEC agreement, signed on April 18, 1957, provides for resumption of intensive operations during the period of Operation Plumbbob conducted by the United States at the Nevada test site, commencing in May and continuing until November 1957. The number of field sampling stations has been increased to 38, as shown on the accompanying list. Thirty-six of these are operated by State, Territorial, and local health agencies, with the remaining two operated by the Public Health Service.

SAMPLING OPERATIONS

Sampling is performed on a 24 hour-per-day, 7 day-per-week basis wherever possible. Of the approximately 15,000 samples taken in 1956, 9 percent of the air samples were invalid because of equipment failures, and 10 reports failed to reach the laboratory.

Sampling operations at each station include (1) the daily radioassay of beta-emitting particulates with relatively long half lives, collected on a filter from approximately 2,000 cubic meters of air, (2) 2 (or more) daily determinations of external gamma radiation levels with a portable survey meter, (3) collection of radioactive fallout by means of the system developed by NYOO of the AEC, and (4) preparation of preliminary reports from which public information might be made available by State and Territorial departments of health.

During 1957 operations, precipitation samples are also being collected.

CENTRAL LABORATORY SERVICES

The radiological health program, Bureau of State Services, of the Public Health Service, maintains the field stations and provides accurate laboratory confirmation of preliminary field measurements.

Through a closely knit communications network, the radiological health program, PHS, and the Division of Biology and Medicine, AEC, cooperate to provide technical guidance to the State and Territorial health departments in the interpretation of day-to-day results and in replying to public inquiries.

PUBLIC INFORMATION AND CLASSIFICATION

No security classification is imposed on the nature of operations or findings of the network. Because of the approximate values derived at the field sampling stations, it has been requested that only the State and Territorial commissioners of health and the Washington headquarters staff be responsible for replying to public inquiry. No attempt was made to relate the network findings back to specific test operations at the Pacific Proving Ground; instead, interpretation of results has been confined simply to reporting the factual data. This apparently satisfied the numerous newspaper inquiries directed to the State and Territorial commissioners of health.

As far as can be determined, the network operations and the immediate availability of its data help explain, to those of the public who inquire, the dis-

semination of radioactive material from nuclear test areas outside of the continental United States, and the levels of activity which might occur in populated areas in the United States as a result. At many of the field sampling sites, there has been almost daily contact between the State health departments and the newspaper services.

PRELIMINARY RESULTS

During the entire 1956–57 sampling period, external gamma background radiation measurements have remained practically constant at all sampling stations. Depending upon the locality, the background varies from 0.01 to 0.035 milliroentgens per hour and, in general, is typical of that locality.

The beta activity of the particulates in air, having gross radioactive half lives longer than several days, showed minimum average concentrations varying from 0.5 to 1.0 uuc/M^3 at the time of measurement (3 to 5 days after collection). An exception was Alaska, where minimum concentrations were about one-fifth or one-tenth those in the United States and Hawaii.

Before, during, and well after the period announced as encompassing Operation Redwing conducted by the United States at the Pacific Proving Ground in 1956, maximums of air concentrations were noted at all sampling stations, each lasting from several days to more than a week. The highest value, 25.7 micromicrocuries per cubic meter of air, was measured in Honolulu, with equally high values being observed in Austin, Tex., Indianapolis, Ind., Springfield, Ill., and Gastonia, N. C. The latter 4 occurred about 55 days after the announced termination of the United States 1956 tests at the Pacific Proving Ground, and it is difficult to associate these maximums with our tests, because of the long time interval.

Table 1 and figure 1, accompanying this report, illustrate the shift to higher air radioactivity levels at areas east and west of the Mississippi River, at Honolulu, and in Alaska, with the passage of time. The most significant shift to higher air activities occurred after September 1, 1956, at least 30 days after the announced termination of our test operations.

It has been possible to analyze a number of the samples find the approximate date of formation. It should be realized that this method indicates, within limits, the formative age of the more recent fission products in each sample, and is not intended to assess more than the short-term significance of the gross beta radioactivity. Figure 2 illustrates the results of this procedure, and strikingly shows that the major portion of the intermediate half-lived fission products which were samples in the United States could not have resulted from announced test series conducted by the United States. During the 1957 operation all samples will be dated.

Since January 1957, and continuing until the present time, air activity levels measured in the United States have been substantially higher at all locations than for comparable periods in previous years by a factor of about 5 to 10. The radiation samples, when dated, show approximate formative ages coinciding to a degree with publicly announced foreign nuclear tests. The effect is most noticeable in precipitation sample, as described in The Distribution of Radioactivity From Rain, by Dr. Lloyd R. Setter and Dr. Conrad P. Straub (presented for publication proceedings, American Geophysical Union Meeting, Washington, D. C., April 29 to May 1, 1957).

The National Committee on Radiation Protection, in NBS Handbook 52, has suggested 10^{-9} uc/ml (1,000 uuc/M^3) as the provisional level of permissible concentrations of unkown mixtures of beta-emitting radioisotopes in air. When it is reduced to 10 percent of that value as suggested for large population groups, namely, 100 uuc/M^3, we realize that the measured levels of beta radioactivity in air, while generally below the recommended value, are more often approaching this level as time goes on.

Radiation surveillance network stations and operators

1–1	Hartford, Conn	Omer C. Sieverding, assistant director, Bureau of Laboratories, Connecticut State Department of Health, State Office Building, Hartford, Conn.
1–2	Lawrence, Mass	James L. Dallas, associate sanitary engineer, Massachusetts State Department of Health, Room 511, State House, Boston, Mass.

Radiation surveillance network stations and operators—Continued

2–1	**Trenton, N. J**	Byron Keene, radiation physicist, Bureau of Adult and Industrial Health, Division of Constructive Health, New Jersey State Department of Health, 17 West State Street, Trenton 7, N. J.
2–2	**Albany, N. Y**	Wallace W. Sanderson, assistant director, Division of Laboratories and Research, New York State Health Department, 84 Holland Avenue, Albany, N. Y.
2–3	**Harrisburg, Pa**	Ronald H. Boyer, assistant industrial hygienist, Bureau of Industrial hygiene, Pennsylvania Department of Health, 1680 South Cameron Street, Harrisburg, Pa.
3–1	**Baltimore, Md**	Kenneth M. Hallam, chemist, Division of Industrial Health and Air Pollution, State Department of Health, 2411 North Charles Street, Baltimore, Md.
3–2	**Washington, D. C**	Dr. Frederick H. Goldman, Chief, Public Health Engineering Division, District of Columbia Department of Public Health, Municipal Building, 300 Indiana Avenue NW., Washington, D. C.
3–3	**Gastonia, N. C**	William N. Long, Gastonia Health Department, Gastonia, N. C.
3–4	**Richmond, Va**	E. C. Meredith, director, Division of Engineering, State Department of Health, 12th and Bank Sts., Richmond, Va.
4–1	**Jacksonville, Fla**	Roe B. Hull, Division of Industrial Hygiene, Florida State Board of Health, 1217 Pearl St., Jacksonville 1, Fla.
4–2	**Atlanta, Ga**	Richard Fetz, Georgia State Department of Public Health, Industrial Hygiene Division, Atlanta 3, Ga.
5–1	**Springfield, Ill**	Robert R. French, sanitary engineer, Division of Sanitary Engineering, State Department of Health, State Office Building, 400 South Spring St., Springfield, Ill.
5–2	**Indianapolis, Ind**	Frank D. Wraight, Bureau of Environmental Sanitation, Indiana State Board of Health, 1330 West Michigan St., Indianapolis, Ind.
5–3	**Lansing, Mich**	Donald E. Van Farowe, chief, Standards and Analysis Section, Division of Occupational Health, Michigan Department of Health, Dewitt Rd., Lansing, Mich.
5–4	**Cincinnati, Ohio**	Dr. Lloyd R. Setter, Robert A. Taft Sanitary Engineering Center, 4676 Columbia Parkway, Cincinnati 26, Ohio
6–1	**Iowa City, Iowa**	Robert L. Morris, State Hygienic Laboratory, 272 Medical Laboratories Bldg., University of Iowa campus, Iowa City, Iowa

Radiation surveillance network stations and operators—Continued

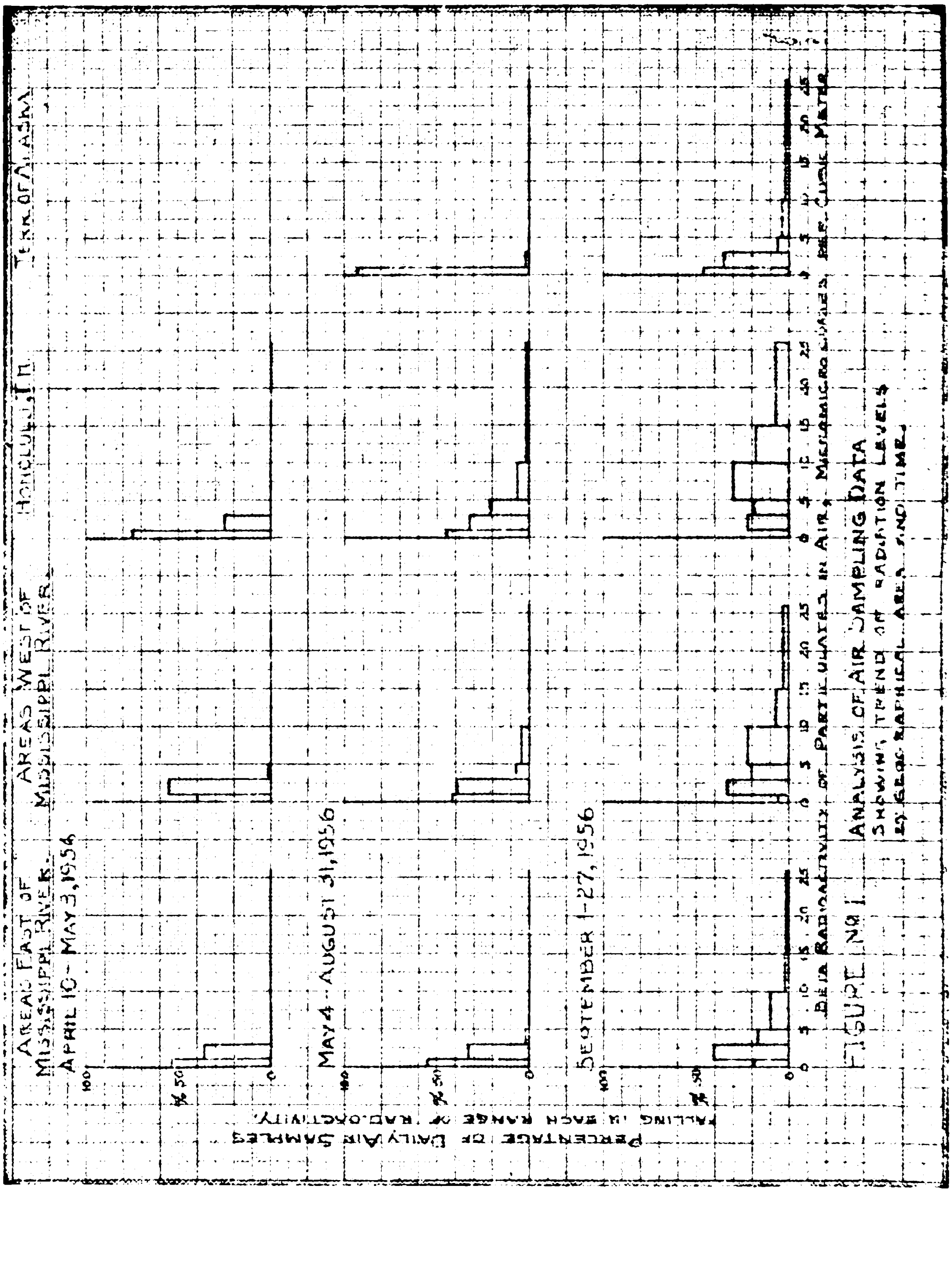
6-2	Minneapolis, Minn	George Raschka, Industrial Health Section, Division of Environmental Sanitation, Minnesota State Department of Health, campus, University of Minnesota, Minneapolis 14, Minn.
6-3	Jefferson City, Mo	Louis Garber, industrial hygiene consultant, Bureau of Public Health Engineering, Missouri Division of Health, State Office Bldg., Jefferson City, Mo.
6-4	Pierre, S. Dak	Donald G. Kurvink, Occupational and Radiological Health, State Department of Health, Pierre, S. Dak.
7-1	New Orleans, La	Warren H. Reinhart, chief, Section of Occupational Health and Safety, Louisiana State Department of Health, 1436 Dryades St., New Orleans, La.
7-2	Oklahoma City, Okla	Loyd F. Pummill, sanitary engineer, State Department of Health, 3400 North Eastern, Oklahoma City 5, Okla.
7-3	Austin, Tex	Martin C. Wukasch, Texas State Department of Health, Division of Sanitary Engineering, 410 East 5th St., Austin, Tex.
7-5	El Paso, Tex	James H. Tillman, City-County Health Department, 118 West Missouri St., El Paso, Tex.
7-6	Little Rock, Ark	Frank Edward Wilson, Bureau of Sanitary Engineering, State Health Department, State capitol grounds, Little Rock, Ark.
8-1	Denver, Colo	William R. Van Nattan, Colorado Department of Public Health, State Office Building, Denver 2, Colo.
8-2	Salt Lake City, Utah	Lynn M. Thatcher, State Department of Health, State Capitol Building, Salt Lake City, Utah
8-3	Cheyenne, Wyo	Robert E. Sundin, Industrial Hygiene Section, Wyoming Department of Public Health, State Office Building, Cheyenne, Wyo.
8-4	Boise, Idaho	Vaughn Anderson, Division of Engineering and Sanitation, Idaho State Board of Health, Post Office Box 649, Boise, Idaho
9-1	Anchorage, Alaska	William B. Page, chief, Environmental Sanitation Section, Arctic Health Research Center, Anchorage, Alaska
9-2	Phoenix, Ariz	George W. Marx, Bureau of Sanitation, State Department of Health, State Office Building, Phoenix, Ariz.
9-3	Berkeley, Calif	Dr. Harold L. Helwig, chief, Air Sanitation Laboratory, California State Department of Health, 2151 Berkeley Way, Berkeley, Calif.
9-4	Los Angeles, Calif	Remo Navone, chief, Branch Public Health Laboratory, California State Department of Health, 1930 Beverly Boulevard, Los Angeles 57, Calif.

Radiation surveillance network stations and operators—Continued

9–5	Honolulu, T. H.	Francis H. Woo, chief, Industrial Hygiene, Department of Health, Territory of Hawaii, Honolulu, T. H.
9–6	Mercury, Nev.	Not operational in 1957 network.
9–7	Portland, Oreg.	Richard E. Hatchard, director, air pollution control, Oregon State Board of Health, 1400 South West Fifth Avenue, Portland, Oreg.
9–8	Seattle, Wash.	Edwin L. Ruppert, Washington State Department of Health, 2120 Smith Tower, Seattle 4, Wash.
9–9	Juneau, Alaska	Ralph B. Williams, director, public health laboratories, Alaska Department of Health, Alaska Office Building, Juneau, Alaska
9–10	Klamath Falls, Oreg.	Max Braden, Klamath County Health Department, Klamath Falls, Oreg.

TABLE 1.—*Analysis of air sampling data, showing the trend of radiation levels in the United States, Hawaii, and Alaska for 3 time intervals: Before, during, and after Operation Redwing*

Geographical area	Time interval, 1956	Numbers of daily air samples, by beta activity level							
		0–1 uuc/M³	1–3 uuc/M³	3–5 uuc/M³	5–10 uuc/M³	5–15 uuc/M³	5–26 uuc/M³	Invalid	Total
Areas east of Mississippi River.	Apr. 10 through May 3.	90	60	0	0	0	0	16	166
	May 4 through August 31.	943	559	24	5	0	0	185	1,716
	Sept. 1 through Sept. 27.	78	170	67	39	7	4	41	406
Areas west of Mississippi River.	Apr. 10 through May 3.	71	99	2	0	0	0	7	179
	May 4 through Aug. 31.	704	663	114	65	7	4	133	1,690
	Sept. 1 through Sept. 27.	24	120	76	82	25	13	29	369
Honolulu, T. H.	Apr. 10 through May 3.	12	4	0	0	0	0	0	16
	May 4 through Aug. 31.	51	86	12	7	2	2	3	113
	Sept. 1 through Sept. 27.	0	6	5	8	5	2	1	27
Territory of Alaska.	May 4 through Aug. 31.	198	4	0	0	0	0	10	212
	Sept. 1 through Sept. 27.	25	15	0	2	1	0	11	54


Areas East of Mississippi River
Areas West of Mississippi River
Honolulu, T.H.
Terr. of Alaska
April 10 - May 3, 1956
May 4 - August 31, 1956
September 1-27, 1956
Beta Radioactivity of Particulates in Air, Micromicrocuries per Cubic Meter
Percentage of Daily Air Samples falling in each range of radioactivity
Figure No 1.
Analysis of Air Sampling Data
Showing trend of radiation levels by geographical area and time.

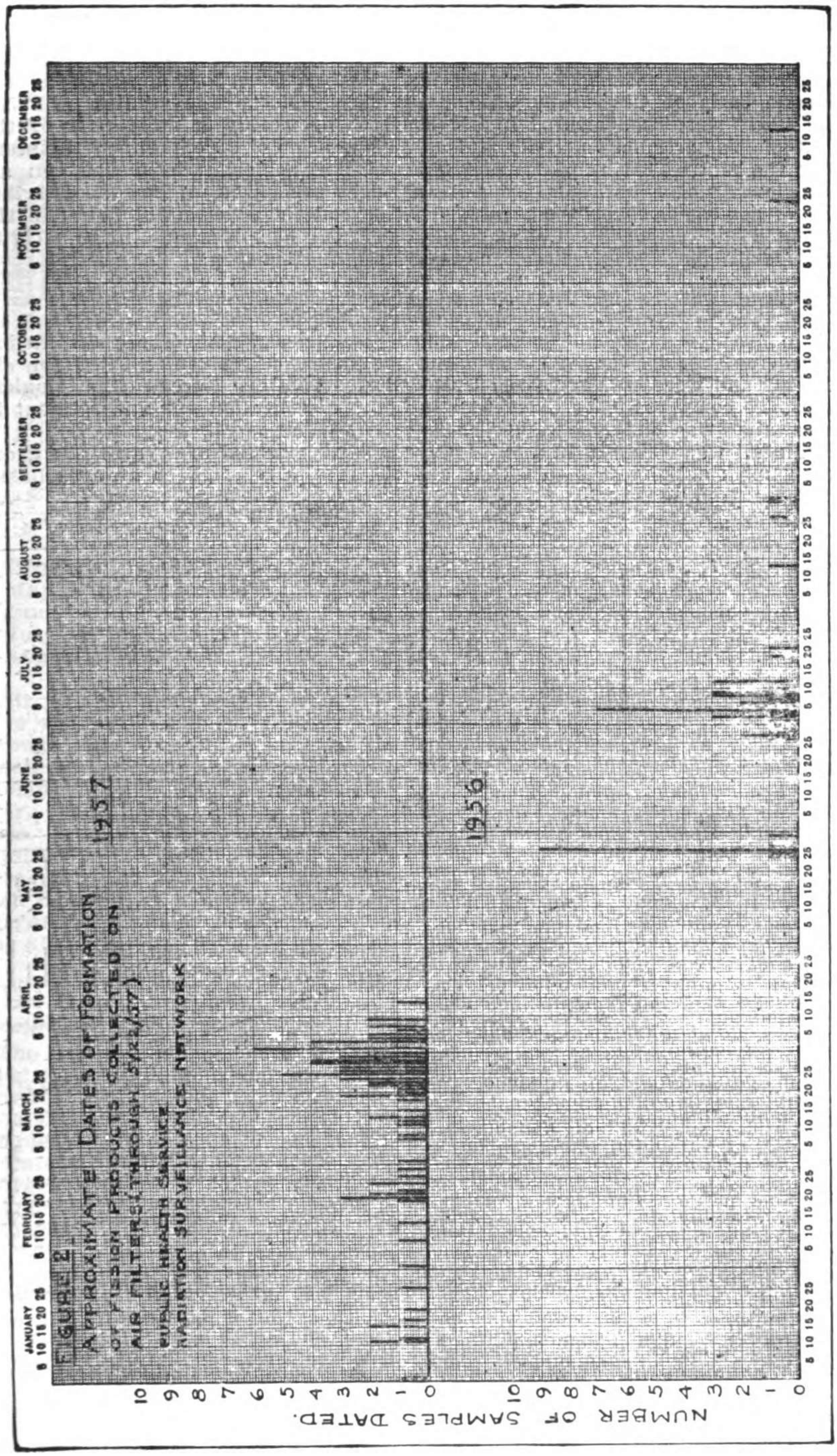


FIGURE 2.
APPROXIMATE DATES OF FORMATION
OF FISSION PRODUCTS COLLECTED ON
AIR FILTERS (THROUGH 5/22/57)
PUBLIC HEALTH SERVICE
RADIATION SURVEILLANCE NETWORK
1957
1956
NUMBER OF SAMPLES DATED.
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER

THE DISTRIBUTION OF RADIOACTIVITY FROM RAIN [1]

Lloyd R. Setter and Conrad P. Straub [2]

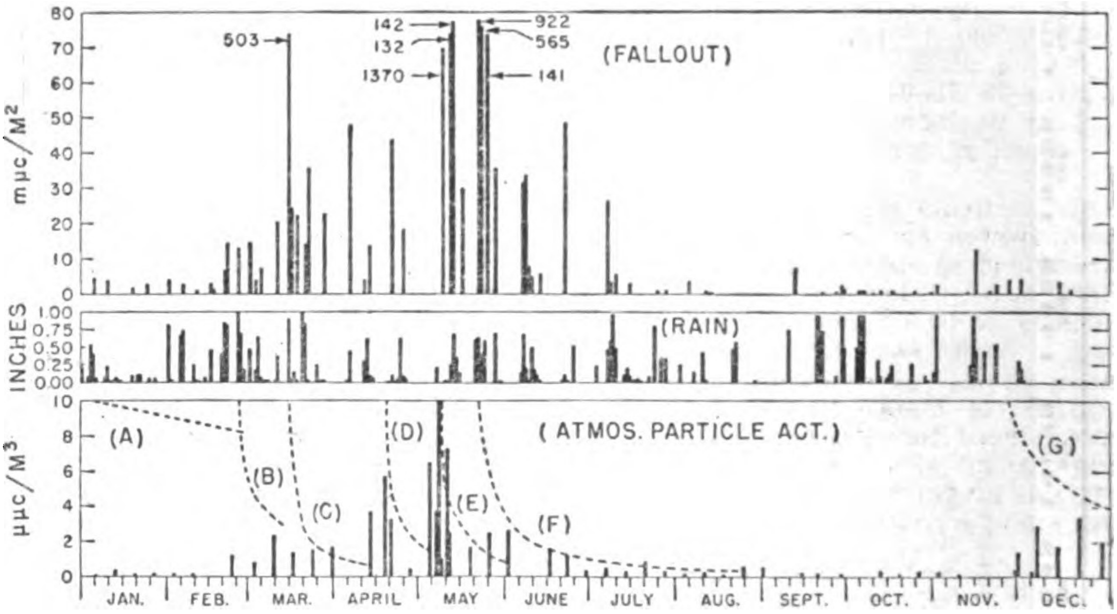
Fallout measurements, largely as precipitation, have been made on a continuous basis at Cincinnati, Ohio, since March 1953. The studies of 1953 [3] and 1954 [4] were implemented in October 1953 by weekly or daily tests of the atmospheric particulate activity and by the operation of an experimental cistern near the site of the rain collector. Correlation is now possible between air particle concentration and rainout (washout by precipitation) and the distribution of activity between the separated solids and the supernatant liquid in the cistern liquid can be determined. This report includes data relating to activity levels in air particulates, rainfall, and certain Ohio rivers.

METHODS

The methods of sample collection have been described.[4] The precipitation values reported in figures 1 and 2 are the means of values reported for six stations and were obtained from United States Weather Bureau climatological data. To compensate for differences in hours of collection some adjustment in these values was made.

Rainfall was collected in a pail-type sampler, processed to dryness, the gross beta-gamma activity was measured, and the results reported on an area basis.

FIGURE 1



RADIATION LEVELS, AIR AND RAINFALL 1955

Date bomb debris formed	*Decay slope*
a. June 4, 1954	1.0
b. February 18, 1955	1.2
c. Marsh 12, 1955	1.0
d. April 15, 1955	1.2
e. May 5, 1955	1.2
f. May 15, 1955	1.2
g. November 5, 1955	1.0

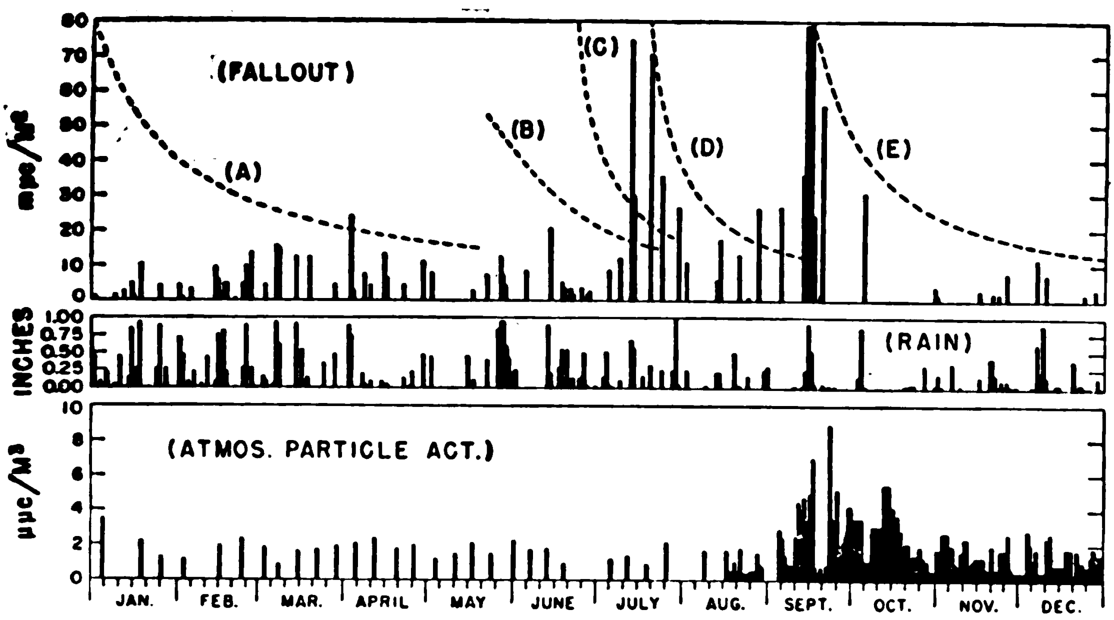
[1] For presentation at the American Geophysical Union Meeting, Washington, D. C., April 29 to May 1, 1957.

[2] Respectively, in charge, radiological investigations, and chief, radiological health program, Robert A. Taft Sanitary Engineering Center, Public Health Service, Department of Health, Education, and Welfare, Cincinnati, Ohio.

[3] Nader, J. S., A. S. Goldin, and L. R. Setter. Radioactive Fallout in Cincinnati Area. Jour. A. W. W. A., 46, 11, 1096 (November 1954).

[4] Setter, L. R., and A. S. Goldin. Radioactive Fallout in Surface Waters. Ind. Eng. Chem., 48, 2, 251 (February 1956).

FIGURE 2



RADIATION LEVELS, AIR AND RAINFALL 1956

Date bomb debris formed	Decay slope
a. December 1, 1955	1.0
b. May 3, 1956	1.0
c. June 13, 1956	1.0
d. July 10, 1956	1.0
e. August 27, 1956	1.0

Air particulate activity from January 1, 1955, to August 1956, was determined from swatch subsamples representing roughly 80 cubic meters of air filtered through glass-fiber filters over a 24-hour period, from the Lincoln Park area, Cincinnati.[5] Since August 1, 1956, the air activity reported was obtained by filtering 20 to 30 cubic meters of air through a membrane (cellulose acetate) filter. With the exception of weekend samples collections were made on a daily basis. Sampling was continuous and was interrupted only during the period required to change the filters. After collection, the membrane filter samples were placed in aluminum dishes, saturated with 95 percent alcohol, ignited, flash flamed with a Meeker burner, and counted for two 8-minute periods in an internal proportional counter. To permit decay of short-lived naturally occurring alpha activity[6] counting was delayed for 48 hours.

RESULTS

Precipitation, air particulate, and fallout activity

The precipitation in inches, air particulate activity in micromicrocuries per cubic meter ($\mu\mu c/m^3$), and the fallout activity in millimicrocuries ($m\mu c$) per liter results have been summarized in figures 1 (1955 data) and 2 (1956 data). From decay studies on rain samples it was also possible to determine the age of the samples. This age, shown with the air activity in figures 1 and 2, was obtained by calculating or estimating the slope of the decay rate. For time intervals between such decay curves, the decay rate of later date was used to correct samples collected during the interval indicated.

In general, the results show that increased air activity results in increased activity in the fallout samples collected. This is particularly true for the samples collected in the spring of 1955 during and following continental weapons tests and to a lesser extent for samples collected following foreign weapons tests activities during fall 1955 or Pacific and foreign tests in 1956.

[5] Tabor, Elbert C. Protein Content of Air—Final Report of Research for the Chemical Corps Biological Warfare Research Laboratories on Contracts Nos. CD-3-3207 and CD-4-4432, USPHS 1956.

[6] Setter, L. R., G. R. Hagee, and C. P. Straub. The Analysis of Radioactivity in Surface Waters: Practical Laboratory Methods. Submitted for publication in the Am. Soc. for Testing Materials, Bull. 1957.

Considering particulate activity in air from stations in the Midwest (Cincinnati, Louisville, St. Louis, Chicago, Minneapolis, and Detroit) the average background level of approxmately 0.05 $\mu\mu c/M^3$ in the fall of 1953 has increased to an arithmetic average level of 0.6 $\mu\mu c/M^3$ in 1954, 1.55 $\mu\mu c/M^3$ in 1955, and 2.26 $\mu\mu c/M^3$ in 1956. During continental tests in 1955, the activity in Cincinnati air (fig. 1) fluctuated from a high of 10 $\mu\mu c/M^3$ of rapidly decaying radioactivity to a low of 0.08 $\mu\mu c/M^3$ of longer lived radioactivity. Less fluctuation in radioactivity levels (8.9 to 0.58 $\mu\mu c/M^3$) was observed during the Pacific and foreign tests of 1956. Presumably this was due to greater diffusion and decay of radioactivity from a more distant source. However, a higher sustaining level of air radioactivity was noted for the entire year.

As shown in figure 1, 15 rain collections made between March 15 and June 25, 1955, showed activity levels above 30 $m\mu c/M^2$, with the level in 7 of these varying from 141 to 1370 $m\mu c/M^2$. From the decay curves indicated, most of this activity was short lived. Relatively little radioactivity was observed in samples collected during the first 2 and last 6 months of 1955, but the activity collected was of longer half life.

A few peaks of high activity were noted (see fig. 2) during July and September 1956, but fallout levels in excess of 10 $m\mu c/M^2$ were common throughout the year. From the decay curves shown it will be seen that most of the activity collected in 1956 was longer lived than that collected during 1955.

Residual fallout

A somewhat better appraisal of the amount of long-lived radioactive fallout may be obtained by considering the cumulative residual deposition. At Cincinnati, and presumably at all nonarid areas several hundred miles removed from the weapons-test site,[7] increased fallout appears to be associated with periods of rainfall and snowfall.

The fallout, identified quite precisely as to age and rate of decay for the more radioactive samples and less accurately for the low-level radioactive samples, has been decayed to the first of each succeeding month. The cummulative residual activity in millimicrocuries per square meter ($m\mu c/M^2$) of earth's surface, assuming no loss, is plotted as shown in figure 3 for each of the 4 years of record from April 1953 to July 1, 1957. In each year there is a peak of activity during or immediately following test operations. High peaks of 1054 $m\mu c/M^2$ on June 1, 1953, and 970 $m\mu c/M^2$ on June 1, 1955, are shown for the 2 years of continental tests (1953 and 1955), whereas longer lived peaks of 110 and 390 $m\mu c/M^2$ were observed on July 1, 1954 and October 1, 1956, respectively. Fallout during the latter periods was from Pacific and foreign test operations. If a 6-month delay is assumed for observed fallout (that is correcting to the following July 1 after a year of accumulation), the residual activity for each year is as follows:

Year of deposition:	*Residual fallout on July 1 following year of deposition* $m\mu c/M^2$
1953	35
1954	35
1955	90
1956	110
Total 1953-566	270

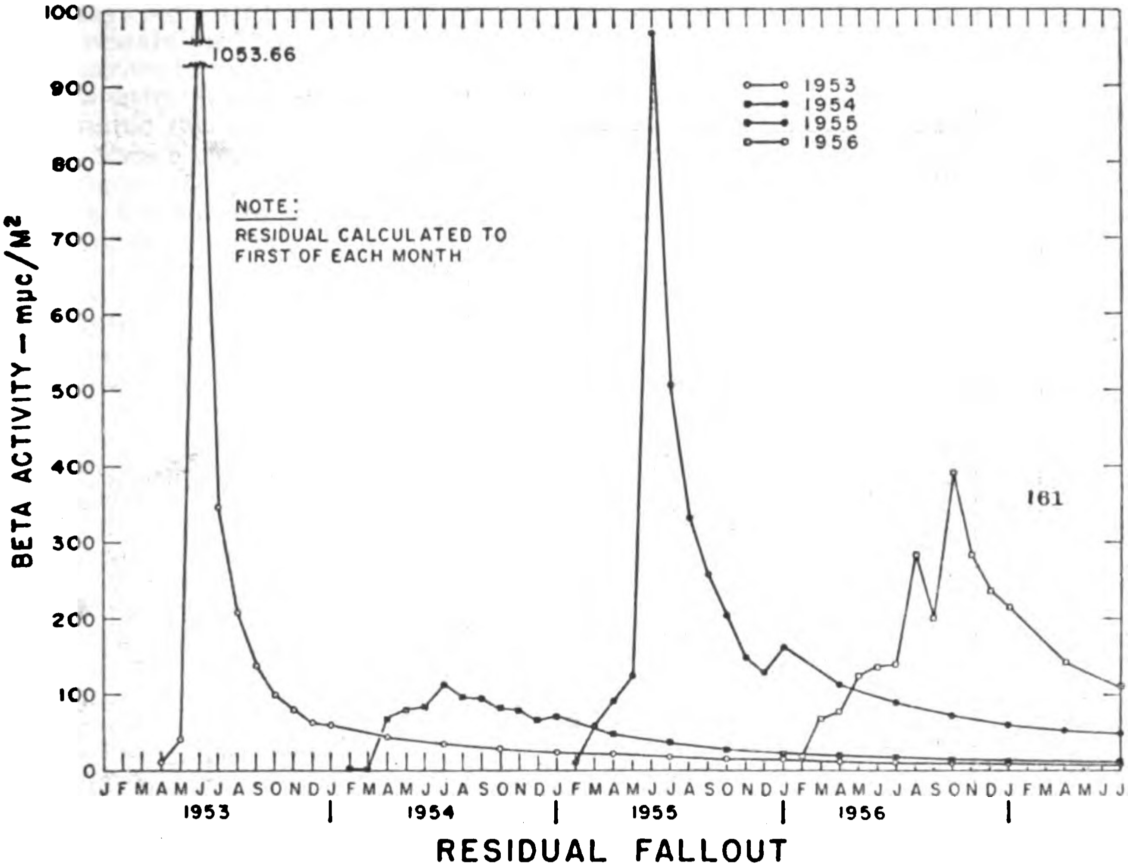
A steeper decay slope is noted on July 1, 1957, for the 1956 fallout, so that the 110 $m\mu c/M^2$ probably contains about as much long-lived activity as does the 1955 fallout. Nevertheless the table clearly shows approximately a threefold increase in fallout for 1955 and 1956 in comparison to 1953 and 1954.

Assuming that the residual fallout as of July 1, of the succeeding year has an average age of 1 year, one may estimate the strontium-yttrium activity which was deposited. According to Hunter and Ballou[8] the combined activity of Sr^{90}–Y^{90} 1 year after formation is 3.9 percent of the residual or 10.5 $m\mu c/M^2$ deposited over the 4 years. This amount, uniformly mixed with 30 in./yr x 4 yr.

[7] List, Robert. Radioactive Fallout in North America From Operation Teapot. USAEC Doc. No. NYO–4696 (February 1956).

[8] Hunter, H. F., and N. E. Ballou. Fission-Product Decay Rates. Nucleonics, 9, 5, C–2 (November 1951).

FIGURE 3



or 120 inches of rain over 4 years gives a Sr^{90}-Y^{90} concentration level of 3.46 $\mu\mu c/L$ as compared to the maximum permissible level of this parent-daughter combination of 800 $\mu\mu c/L$.[9]

Distribution of fallout in cistern water

Early in 1954, an experimental cistern, consisting of a hopper-bottomed tank of 2.62M[3] capacity, was installed to collect precipitation from a portion of the roof of an adjacent building. The cistern was in operation from February 10, 1954, to March 7, 1956, and from July 5 to September 25, 1956. During this period, settled cistern water was withdrawn and tested and on 15 occasions the settled sludge was removed and tested. The more significant data from cistern operation are presented in table 1. The total activity found in the cistern water, sludge, and sludge supernatant are indicated in column 7: Sludge supernatant consisted of a known quantity of cistern water (up to 50 liters) required to wash down the cistern sides and bottom. The washed sludge was settled for 10 to 15 minutes and the supernatant removed by decantation. This supernatant was sampled and tested for dissolved and suspended activity in the same manner that the citern water itself was tested. The sludge and supernatant solids contained in the roof drainage amounted to an average of 30 p. p. m. of dry solids (ranging from 9 to 71 p. p. m.) of which about 30 percent were volatile.

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[9] Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and in Water. National Bureau of Standards Handbook No. 52, U. S. Department of Commerce. March 20, 1953.

TABLE 1.—*The distribution of fallout in cistern water*

Series No.	Date of accounting	Precipitation, inches	Ext. date [1]	Age of bomb-debris days	Total precipitation inches	Gross Beta Radioactivity: Recovered in cistern (μc)	Gross Beta Radioactivity: In rain (μc)	Gross Beta Radioactivity: Dissolved in cistern water (percent)	Gross Beta Radioactivity: Suspended in cistern water (percent)	Gross Beta Radioactivity: In cistern dissolved ($\mu\mu c/L$)	Gross Beta Radioactivity: Water total ($\mu\mu c/L$)
1	Mar. 4, 1955	19	Mar. 8	19-300	6.34	2.86	1.40	14	77	69	445
2	Mar. 16, 1955	5	Mar. 19	7-30	1.37	10.00	9.71	53	22	4,160	5,890
3	Mar. 21, 1955	4	Mar. 22	10	1.96	1.02	.95	30	17	163	256
4	May 5, 1955	16	May 11	20-55	2.79	1.46	2.15	46	13	262	337
5	May 17, 1955	6	May 26	15	1.59	3.48	7.16	28	12	660	950
6	June 21, 1955	14	June 29	37	4.62	8.02	8.60	38	33	720	1,310
7	July 14, 1955	11	July 20	60	3.68	1.55	2.07	56	1	259	263
8	Aug. 24 1955	16	Aug. 26	101	3.07	.33	.28	26	7	34	43
9	Sept. 28, 1955	6	Oct. 4	136	3.50	.15	.34	49	7	22	25
10	Oct. 25, 1955	11	Nov. 10	163	6.01	.17	.20	23	8	7	10
11	Nov. 18, 1955	6	Nov. 30	187	2.93	.11	.53	39	5	24	23
12	Feb. 9, 1956	36	Feb. 9	64-270	9.32	1.16	1.14	56	34	76	123
13	Mar. 7, 1956	11	Mar. 7	36-98	5.08	1.65	1.83	37	27	157	269
14	July 27, 1956	8	July 27	17-44	2.08	4.14	4.66	19	23	410	908
15	Sept. 25, 1956	21	Sept. 25	15-77	5.58	7.81	9.40	55	22	762	1,070
Total, 1 to 15	----------	193	----------	----------	59.92	43.94	50.40	[2] 40	[2] 25	[2] 322	[2] 524

[1] All measurements in a series extrapolated for decay to this date.

[2] Obtained from activity (total or dissolved) ÷ total rainfall.

During the 16-month period of cistern operation, the rain collected contained a total of 50.4 μc of beta activity (col. 8) from bomb debris estimated to be 10 to 300 days old. Of this total, 36.72 μc or 73 percent was recovered from the cistern. The remaining 27 percent represents activity fixed to the asphalt roof shingles, and errors in measurement. It is interesting to note that estimations based on the activity found on washed shingle stone separated from the cistern sludge accounted for much more than the 27 percent unaccounted-for activity. However, longer contact was possible in the case of the shingle stone contained in the sludge in contrast to the contact time during roof runoff.

The soluble activity in the cistern water varied from 14 to 55 percent or amounted to 48 percent (weighted average). There seems to be no clear-cut relationship between the percentage of dissolved activity and the age of bomb debris. This is contrary to the observation made in 1953[8] that the percentage of solubility in the rain was less with shorter lived radioactivity. Other factors, such as nonradioactive air pollutants, the time radioactive particles were exposed to moisture, the size and chemical structure of radioactive particles, and, possibly, the inflow of upper atmosphere contaminants to lower levels in the rainout zone, play a role in forming the soluble fraction. The concentration of dissolved activity in cistern water varied from 7 to 4,160 or an average of 322 $\mu\mu c/L$. Lower values (less than 76 $\mu\mu c/L$) were observed during periods when the bulk of the activity was estimated to be older than 100 days, whereas, for activity 7 to 98 days in age, the dissolved activity was 157 $\mu\mu c/L$ or more.

The percentage of activity associated with the suspended solids ranged from 1 to 77 percent, with an average value of about 25 percent.

In summary, the cistern study reveals that slightly more than one-half of the activity found in the cistern water was soluble and that up to a third of the activity would be associated with the suspended solids. Over two-thirds of the insoluble activity settles as a sludge (1.5 kg. dry weight) having an activity of 10 μc/kg. (dry weight). Septicity resulted in further solution of activity, but diffusion into the supernatant was minimal if the sludge was undisturbed.

The distribution of fallout in surface waters

Nine grab and seven composite (7- to 10-day) samples from 13 stations on the Ohio River from Pittsburgh, Pa., to Louisville, Ky., were collected between December 27, 1955, to April 20, 1956, in a cooperative study with the Ohio River Valley Water Sanitation Commission. The maximum beta activity found was 100 $\mu\mu c/L$ as compared to an arithmetic average value of 27.5 $\mu\mu c/L$ of which 15 $\mu\mu c/L$ was in solution.

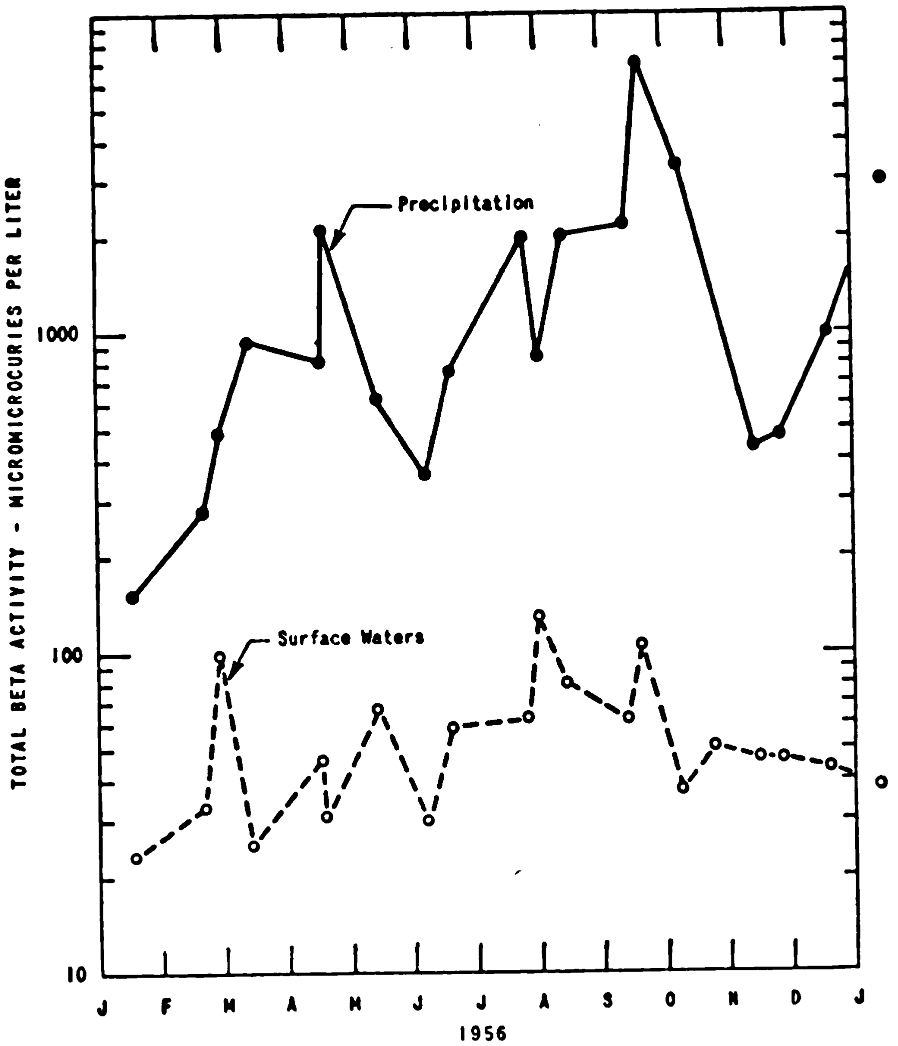
Additional samples were collected on the tributaries of the Ohio River and tested. Through the courtesy of Mr. F. H. Waring, chief sanitary engineer, division of sanitary engineering, Ohio State Board of Health, some of these results are included in table 2 and figure 4. The samples were collected from the Little Miami, the Great Miami, and Scioto Rivers. Included in the table are maximum and average activity levels of the surface waters as well as Cincinnati rainout results for collections made between river samplings.

TABLE 2.—*The radioactivity of Ohio surface water, 1956, as compared to rainout*

Date of collection	Stream stations [1]	Stream-water activity, μμc/L				Rain, inches	Rainout μμc/L [2]	
		Maximum		Average				
		Dissolved	Total	Dissolved	Total		Dissolved	Total
Jan. 17	A	19	42	6	23	2.5	50	150
Feb. 20	A	----------	43	----------	33	6.8	160	280
Feb. 28	B	80	141	52	99	1.2	100	490
Mar. 13	A	----------	38	----------	25	2.0	300	930
Apr. 17	B	38	54	29	46	3.7	----------	830
Apr. 24	A	25	40	16	31	.2	----------	2,120
May 14	A	64	87	43	67	1.2	----------	620
June 6	B	29	50	10	30	4.6	140	380
June 18	A	30	66	23	58	1.1	420	760
July 25	B	45	79	44	62	5.0	----------	2,000
July 31	A	80	217	64	130	1.3	510	840
Aug. 15	A	51	140	32	80	.6	1,310	2,040
Sept. 11	A	84	116	35	62	1.2	1,420	2,180
Sept. 19	B	89	178	57	105	1.7	2,200	7,000
Oct. 8	B	27	44	22	37	1.1	1,320	3,300
Oct. 23	A	30	158	20	51	0	----------	----------
Nov. 14	B	36	46	31	47	.5	317	440
Nov. 26	A	60	68	39	47	.6	----------	478
Dec. 18	A	34	69	23	44	1.09	621	932
Jan. 15	B	26	42	20	38	1.42	193	2,941

[1] Ohio State Board of Health data on:
A—Little Miami River at Newtown and 5 stations on Great Miami River from river mile 24.8 to 26.6.
B—Four stations on Scioto River from river mile 15 to 140.
[2] Weighted average activity of rain at Cincinnati collected between dates of stream sampling.

FIGURE 4



A COMPARISON OF CINCINNATI FALLOUT IN RAIN
WITH THE ACTIVITY OF OHIO STREAM WATER

The results show a maximum dissolved activity level of less than 90 $\mu\mu c/L$ compared to a maximum total (suspended and dissolved) activity of 217 $\mu\mu c/L$ for the year. The average dissolved activity appears to represent about one-half of the total activity indicated for a given date of sampling. The average total activity for each sampling date fluctuated from 25 to 130 $\mu\mu c/L$, depending to some degree on the activity of the more recent rains. The yearly geometric average values for the surface streams are 27 $\mu\mu c/L$ for dissolved or a total beta activity of 50 $\mu\mu c/L$ as compared to 389 and 974 $\mu\mu c/L$ respectively, for Cincinnati rain. The average yearly removal by natural agents is, therefore, 93 to 95 percent for dissolved and total activity, respectively. Actually, the removals may be even greater inasmuch as some of these streams are known to receive radioactive materials from industrial, research, and medical facilities.

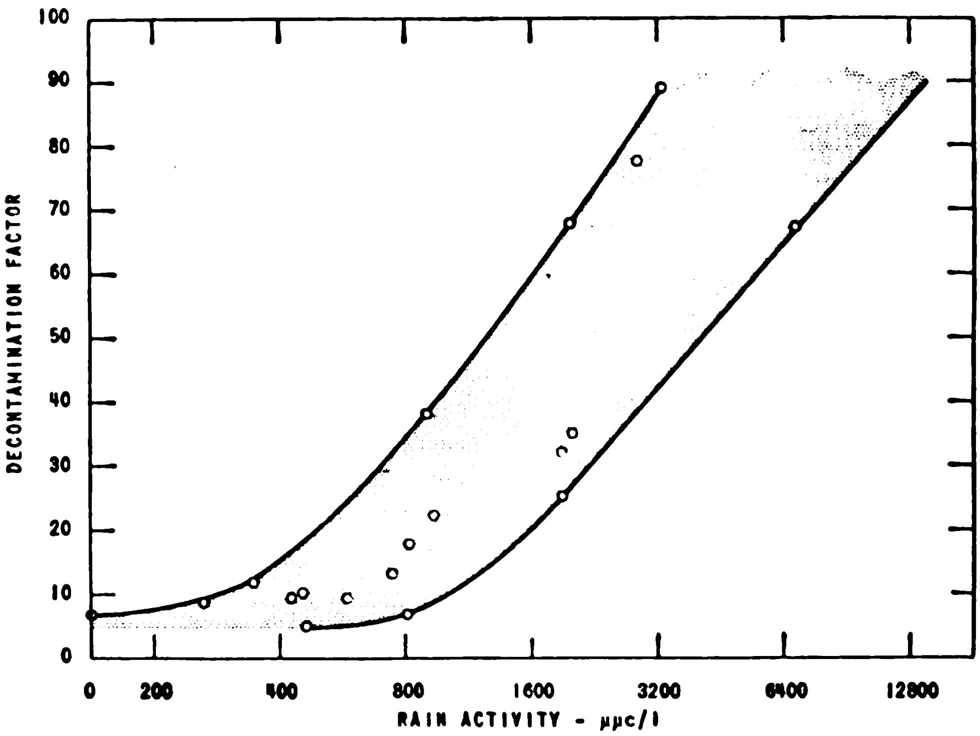
The plotted results (fig. 4) more clearly define the relationship of total rain activity (from Cincinnati fallout) with that found at stream stations up to several hundred miles distance. Obviously, Cincinnati rain and activity measurements can be expected to be at considerable variance to true values at these remote distances. Nevertheless, general trends may be observed and the desirability of establishing more rain monitoring stations as apparent. The rain data indicate a sharp increase (150 to 2,100 $\mu\mu c/L$) during the first of the year, then, following a drop in May and June, a second rise to levels of 2,000 to 7,000 by September. During the last 3 months of the year, the rain activity receded. Lower levels of activity correspond to longer lived bomb debris and high levels correspond to young (short-lived), rapidly decaying, fission products.

The ratio of total rain activity to total surface-water activity was determined for each month, and reported in terms of the decontamination factor (rainout or fallout activity over surface-water activity). These decontamination values were plotted against the rain activity as shown in figure 5. It will be seen that removal by natural agents increases with increased activity of the rain. Comparable in many respects with other pollutants, the plotted values indicate the application of the law of diminishing returns; i. e., high decontamination factors in the order of 65 to 90 (98.5 to 98.9 percent removal) for relatively young bomb debris and decontamination factors of 5 to 10 (80 to 90 percent removal) for lower level, longer lived activity.

For a direct comparison of the distribution of rainout in surface waters of these streams in the general area of Cincinnati, the rainout (corrected for decay to the end of a sampling series) and cistern-water activity of series 11 to 15 (table 1) have been summarized in table 3 with stream tests of appropriate date.

It is seen that subsidence in a cistern results in some purification (21 to 38 percent), adsorption on surfaces such as vegetation, soil and turbidity, percolation, and dilution play important roles in reducing the total activity of rain (91 to 92 percent).

FIGURE 5



THE DECONTAMINATION OF RAIN BY NATURAL AGENCIES

TABLE 3.—*Comparative beta activity of rain, cistern, and stream waters*

[Results in micromicrocuries per liter]

Series dates	Dissolved activity			Total activity		
	Rain	Cistern	Stream	Rain	Cistern	Stream
Nov. 18 to Feb. 9	54	76.0	6.0	130	123.0	0.23.0
Feb. 9 to Mar. 7	152	157.0	52.0	390	269.0	33.0-99.0
July 5-27	1,430	410.0	44.0	2,420	908.0	62.0
July 27 to Sept. 25	800	762.0	32.0-64.0	1,830	1,070.0	62.0-130.0
Geometric means	311	247.0	28.4	689	424.0	54.8
Percent removal compared to rainfall	....	20.6	91.0	....	38.5	92.0

Radsafe Emergency Instructions for Populated Islands

1. The commander, JTF–7, has designated a representative for each off-site location outside the PPG. For the populated islands near the PPG, the representative is responsible for the radiological safety of the local population and the members of the task force.

2. The representative of the task force commander is provided guidance as follows:

(a) The Marshallese magistrate and irou if on hand and the Marshallese health aid and council on each atoll or island should be assured that every precaution has been taken to prevent exposure of the natives to radiation hazards resulting from fallout.

(b) The representative will consult with the local magistrate to insure that a method exists whereby all residents of an atoll may be summoned to a central location and evacuated by air or water transportation if a fallout emergency exists. A fallout emergency will be determined by the commander, JTF–7; however, the local representative will assume that a fallout emergency exists at such time as radiological survey instruments, when held at a position 3 feet above the ground, indicate a rate of 1r./hr.

(c) Should evacuation by air be necessary, baggage will be limited to that which each individual can carry or approximately 50 pounds. Whether evacuation is achieved by sea or air, no animals will be evacuated. A tabulation of animals left behind should be made as soon as possible to insure the accuracy of claims against the Government.

(d) The local magistrate should be informed that in event of an unforeseen emergency, doctors will be flown from the United States by special airlift to care for local inhabitants who will be evacuated to Kwajalein Atoll and that evacuation plans are in existence to permit the task force to cope with any emergency.

(e) Fallout of a dangerous nature can be suspected by the presence of a saltlike precipitate or unexpected mist. Should such an event take place, it should be confirmed by monitoring.

3. The representative will arrange through the local magistrate and native health aid to inform the Marshallese of the basic health measures that they may take to protect themselves from danger in case fallout is suspected or confirmed. These measures are:

(a) Remain indoors or under cover to protect themselves from the falling or settling radioactive particles.

(b) If particles settle on clothing, dust and shake off clothing.

(c) Bathe and keep clean. Particular attention should be given to washing under the arms, the groin, face, and hair.

(d) Keep food covered to prevent ingestion of fallout particles.

(e) Should the readings exceed 5 r./hr. it is recommended that the natives be advised to stand out in the water (ocean) and immerse themselves as often as practicable or keep themselves under water. This recommendation is based on the fact that water does extremely well in attenuating radiation.

(A report of the Radiological Health Branch, Bureau of State Services, Public Health Service, is inserted at this point in addition to the material submitted.)

Radiological Health Branch,
Bureau of State Services,
Public Health Service,
October 1952.

Summary of the Reported Radiation Exposure in the United States

I. Introduction

The program of the Radiological Health Branch, Public Health Service, is directed toward preventing the impairment of human well-being from accidental or unwise exposure to harmful amounts of ionizing radiations and toward improvement of health through judicious use of these radiations. This program can best be accomplished through cooperative efforts of the Radiological Health Branch and the State and local health agencies.

In order to pursue such an objective effectively, knowledge as to the sources of exposure of human beings to ionizing radiation in the United States, the relative importance of these exposures, and the total effect of them on the health of the Nation is a necessity.

This paper summarizes the available unclassified published data on current sources of radiation exposure in the United States and their relative quantitative importance. It is expected that the future will bring nuclear reactors for power purposes into widespread use. The quantities of radioactive materials involved will dwarf the presently produced sources of ionizing radiation. The competence of the health profession to cope with the increased problems arising from these new sources of radiation will be determined by the training and experience of its members in handling present radiological public health problems. Now is the time to prepare to meet the health problems of the nuclear-power industry.

II. SOURCES OF RADIATION EXPOSURE

The existing radiation exposure in the United States (exclusive of natural background radiation) originates from the use of radiation-producing machines and radioactive substances in many fields—broadly covered by the terms "the healing arts," "industrial usage," "commercial usage," and "investigative (research) usage."

The following table lists the sources of radiation exposure in the United States about which the Radiological Health Branch has been able to collect information.

Data currently pertinent to radiological health surveys

Radiation source	Cause of exposure	Where found	Persons exposed
X-ray	Healing arts:		
	Diagnosis (radiography and fluoroscopy) and therapy.	Hospitals, clinics, private practice, dentistry, dermatology, veterinary practice, chiropody, osteopathy.	Doctors, nurses, technicians, dentists, patients, persons holding or positioning patients, X-ray unit repairmen, bystanders and persons in adjoining offices or on floors above or below.
	Mobile and portable chest X-ray units; multiphasic testing units.	Trailer stations, community buildings, fairgrounds, etc.	Same as above with additional community participants, volunteer workers, local health department staff, etc.
	Industry:		
	(1) Radiography (permanent mobile and portable units); inspection of welds, castings, pressure vessels, and parts.	Nonferrous foundries, boiler-shop products, aircraft engines and parts, metal-working machines, steel foundries, gray-iron foundries, tires, V-belts, and inner tubes, propeller blades, electric welding apparatus, bronze babbitt, special industrial machinery, general industrial machinery, models and patterns, railroad cars and street cars, carbon and graphite products, motor vehicle, motor-vehicle parts, vacuum cleaners, motor, generator and motor generators, electric lamps, business machines.	Operators, observers, bystanders, persons in adjoining rooms, repairmen.
	(2) Fluoroscopy:		
	Inspection devices:		
	(a) Manufactured products	(1) Tires, V-belts and inner tubes, carbon and graphite products, vacuum cleaners, rubber industry, electrical equipment for industrial use.	Operator, observers, bystanders, repairmen.
		(2) Food-processing and packing plants	Operator.
	(b) personnel and packages	(1) Prisons, factories, defense plants, police, post office.	Operator, "patient," repairmen.
	(3) High-vacuum electronic tubes	Electronic tube manufacturers and users, testing and operation of the tubes.	Testers, observers, operators, bystanders.
	(4) Theater or projection type TV tubes	Theaters	Operator, repairmen, persons near tube face.
	Commercial usage: (1) Shoefitting	Shoestores	Shoe salesmen, customers, clerks, bystanders, repairmen.
	Research:		
	(1) Variations in electric potentials	Industrial oscillographs	Technicians, experimenters, and repairmen.
	(2) X-ray effects and diffraction studies	Research laboratories, educational institutions.	Do.
	(3) Microscopy-electron microscopes	do	Do.
	Accidents	In all phases	Potentially all users.

Data currently pertinent to radiological health surveys—Continued

Radiation source	Cause of exposure	Where found	Persons exposed
Cathode rays	Sterilization:		
	(1) Food	Food industry	Operator, repairmen.
	(2) Drugs	Drug industry	Do.
AEC distributed radioisotopes (does not include radium).	Transportation of isotopes	AEC to user	Carriers.
	Medical application. Diagnosis and therapy	Hospitals, clinics, private practice, pharmaceutical houses.	Laboratory personnel, doctors, nurses, technicians, patients, persons close to patients, persons handling clothing, bedding, etc., of patients.
	Industrial application (partially research):		
	(1) Radiography (cobalt 60) thickness gages, liquid level gages, density meters.	Automobile companies, oil industry, coating industry, steel companies.	Workmen, operators, bystanders, technicians.
	(2) Movable sources, liquid flow through pipes, location of "go-devil".	Rubber industry, pipeline industry, soap companies, laundry equipment manufacturers, coke industry, metallurgy.	Do.
	(3) Tracers, friction, wear, solid diffusion, detergency, mineral flotation, movement of preservatives, role of catalysts, Fischer-Tropsch synthesis, source of coke sulfur.	Industrial laboratories and test sites	Do.
	Research:		
	(1) Animal and plant physiology	Academic institutions, research groups	Laboratory personnel.
	(2) Bacteriology		Do.
	(3) Chemistry		Do.
	(4) Physics		Do.
	(5) Fundamental medical	U. S. Public Health Service (NIH)	Do.
	Isotope chemistry: (1) Preparations of radioisotopes for special uses.	Industrial laboratories	Do.
Non-AEC distributed radioisotopes (cyclotron produced).	Medical, industrial, research applications	Medical and industrial laboratories, colleges and universities.	Do.
All distributed radioisotopes (does not include radium).	Wastes	Air decontamination, soil contamination, water contamination.	Potentially all users, sewage-works operators, plumbers and persons downstream or downwind from user.
	Accidents	In all phases	Potentially all users.
Fission products	Industrial application	Industry	Few at present. (Field should expand.)
	(1) Activation of phosphors.		
	(2) Static eliminators.		
	(3) Fluorescent light tubes.		
	(4) Instruments containing radiation sources.		
	(5) Sterilization of food and drugs.		

Radium	**Transportation of source**	All sources are portable	Carriers.
	Medical application:		
	(1) **Preparation of radon needles**	**Hospital, clinics**	Laboratory personnel.
	(2) **Therapy (radon and radium)**	do	Laboratory and medical personnel, patients, persons near patients.
	Industrial application:		
	(1) **Radiography**	Inspection of welds, castings, pressure vessels.	Operation personnel.
	(2) **Static eliminators**	Coating industry, textile industry, all paper trades, printing, photographic processing, plastic manufacturing, telephone companies.	Personnel nearby machinery, maintenance and repairmen.
	(3) Activation of phosphors	Sign companies	Workers.
	(4) Luminous compounds	Radium dial industry	Workers, bystanders, users of product, personnel handling storage of products.
	Radium reprocessing	Radium industry	Workers.
	Accidents	In all phases	
Polonium	Industrial applications:		
	(1) Static eliminators	Printing shops	Manufacturers and users.
	(2) Film brushes	Film companies	Do.
	(3) Activation of phosphors	Sign companies	Do.
	(4) Spark plugs	Spark-plug manufacturers	Do.
Thorium	Industrial and research applications	Gas mantle manufacturers, research groups (neutron sources), thorium salt manufacturing and compounding.	Manufacturers (research personnel) and users.
Neutron sources (radium-beryllium)	Research application	Research institutions	Workers, handlers.
Radioactive scrap	Contaminated platinum and gold laboratory scrap and equipment.	Precious metals reclaiming companies	Process operators, sweepers, receiving clerks, stock handlers.
Nuclear reactors	Research, educational, industrial, medical, and military applications.	Educational institutions and industry	Persons working around reactors and handling the products.
	Wastes	Air contamination, soil contamination, water contamination.	Surrounding populace.
	Accidents:		
Raw materials for nuclear reactors	Uranium mining and milling, handling and shipping.	Transportation centers and Colorado Plateau.	Mine and mill workers, transporting workers, processing workers.
Particle accelerators	Industrial, medical, and military research.	Educational institutions	Research personnel.
Atomic weapons	Weapons tests	Air contamination, soil contamination, water contamination, food contamination.	Detectable in all United States.
AEC installations	Plant wastes	Air contamination, soil contamination, water contamination.	Environment surrounding various Atomic Energy Commission sites.

NOTE.—This chart represents a revised version of an earlier chart prepared by the Radiological Health Branch. Information furnished by the New Jersey State Health Department was utilized in the preparation of the revised chart.

III. RADIATION EXPOSURES

A. *Background radiation*

The human race has always been exposed to some ionizing radiation. It is continually being irradiated by radiation from natural sources in the general environment such as uranium, thorium, actinium, radium, radon, and their decay products, from cosmic radiation, and from cosmic-ray induced radioactive materials (1). The aggregate of these radiation sources is known as the natural background radiation. A person who lives to be 70 years of age is exposed to a total of about 9 roentgens background radiation during his lifetime (2).

B. *X-ray in the "healing arts"*

There are more than 125,000 X-ray units in the United States being used for diagnosis and therapy. Some 50,000 of these units are used by general practitioners, physician specialists, radiologists, and in hospitals and clinics (3). Approximately 65,000 of the units are used by dentists (4). It is estimated that some 11,000 are being used by doctors of osteopathy and doctors of chiropractic (5).

There are more than 215,000 operating personnel potentially exposed to radiation in the use of these X-ray units in the United States. These include some 3,000 radiologists devoting full time to their specialty, 500 physicians devoting most of their time to radiology, 600 physicians who are second- and third-year residents in radiology, 31,000 general practitioners and physician specialists owning their own equipment (3), 67,000 dentists utilizing X-ray equipment (4), and some 11,000 osteopaths and chiropractors using X-ray equipment (5). In addition, there are some 40,000 X-ray technicians (6) and probably close to 50,000 dental technicians and assistants (7) (8) currently potentially exposed to radiation. This listing undoubtedly omits many nurses, clerks, attendants, technicians, and others also exposed more or less often to radiation.

Many instances of excessive exposure of X-ray personnel in the United States are reported in the literature (9), (10), (11), (12). However, few specific data are available regarding average exposures for such workers. In one 9-month survey (13) of personnel in 4 X-ray departments, it was found that about 0.5 percent of the weekly exposures exceeded 0.3 roentgen. However, 97 percent were less than 0.05 roentgen. In a similar 3-week survey (13) of personnel in doctors' and dentists' offices and X-ray departments, 3 percent of the weekly exposures exceeded 0.3 roentgen with 81.5 percent being less than 0.05 roentgen. Surveys of United States Public Health Service hospitals by the Radiological Health Training Section, Cincinnati, Ohio (14), have revealed exposures ranging from 0 to 0.46 roentgen per 2-week periods for X-ray personnel. It has also been reported (15) that an appreciable fraction of radiologists experience exposures on the average of more than 0.1 roentgen per day and that 20 percent of the personnel operating photofluorographic equipment exceed 0.3 roentgen per week (16). For dental X-ray it has been reported (17) that the operator receives approximately 0.1 roentgen of general body exposure per 8 examinations of the mouth, each of which consists of a series of 103-second exposures. This assumes careful operation of the unit. Dental operators conducting mass dental X-ray surveys can easily receive present-day maximum allowable radiation dosages, even with some rotation of operators. Personnel in the immediate area of such dental X-ray units can receive appreciable percentages of daily and weekly maximum allowable limits (18).

In the United States, about 2,500,000 persons are seen each day by physicians. A large number of these people have some X-ray diagnostic procedure performed upon them by the physicians and, in addition, more than 82,000 of them are referred to radiologists (3).

Radiologists give approximately 25 million X-ray examinations annually (3). The following table summarizes the data relative to radiation exposures resulting from these examinations. These data have been obtained by the Radiological Health Branch from the published literature (2), (3), (15), (17), (19) through (28).

TABLE I.—*X-ray examinations*

Type	Average dosage (roentgens)	Relative distribution of each type	Roentgen dosage for average examination
		Percent	
Radiographic	2.7	51.88	11
Photofluorographic	1.0	33.64	
Fluoroscopic	65.0	14.48	

Probably the largest single contributing source to the total medical radiation exposure in the United States is the mass chest X-ray survey for tuberculosis. An estimate for 1950 as to the number of persons given chest X-rays in such surveys would be about 15 million (29). A portion of the 25 million X-ray examinations given annually to persons seen by physicians is probably included in the 16 million chest X-rays because of inherent overlap of the reporting procedures. Most of the X-rays given in the mass survey are of the photofluorographic type. This type of examination results in about 1.0 roentgen exposure to the chest of the patient (15) (21).

More than 4 million X-ray *treatments* are given annually to the 82,000 persons referred daily to radiologists (3). These treatments are confined as a rule to a very small portion of the patient's body. The average dosage received is of the order of 6,000 to 7,000 roentgens per treatment (30) through (34).

It has been estimated that in 1949 60 million persons (40 percent of the population) in the United States visited their dentists (8). Some 84 million roentgenograms are taken annually for dental X-ray purposes (35). The average exposure to the mouth of the patient is about 5 roentgens per film (36). Total body irradiation is a fraction of this amount.

C. X-ray in industry

Industrial X-ray devices include primarily (*a*) radiographic and fluoroscopic units used for the determination of defects in castings, fabricated structures, and welds, and (*b*) fluoroscopic units used for the detection of foreign material as in packaged foods.

It is estimated that there are at present approximately 800 active industrial *radiographic installations* in the United States (38). The total number of X-ray *units* (both radiographic and fluoroscopic) in use in industry is probably about 2,000 (40).

In a survey of 61 industrial radiographic X-ray units in Ohio (37) it was found that some 400 persons were potentially exposed. Applying this ratio to the 800 active industrial radiographic installations in the United States (assuming 1 unit per installation), it can be estimated that some 5,000 persons are potentially exposed to radiation from industrial radiographic installations in this country. Numbers of personnel exposed in the use of industrial fluoroscopic units are not known.

The hazards of X-radiation in industry are due to the high intensities employed, the frequency of operation (11), and the use of "homemade" or makeshift equipment or equipment originally designed for other purposes. It is not unusual for one radiographic installation to expose a thousand films in 1 day (39). Energy levels for radiographic installations range up to greater than 1,000 kilovolts. The use of makeshift equipment is especially hazardous in industrial fluoroscopy (39). However, this does not mean to imply, ipso facto, that all other fluoroscopy units are absolutely safe regardless of the manner of their operation.

Exposure levels for personnel in industry depend upon the installation. Most installations were designed and the personnel assignments planned so as to limit personnel exposures to the levels recommended in the National Bureau of Standards Handbook current at the time the equipment was built. However, the continual revision downward of maximum permissible exposure limits (currently 0.3 roentgen per week) calls for a reevaluation, by survey, of the older installations.

In the use of fluoroscopy for the scanning of personnel, such as at prisons, exposures of 0.045 to 0.09 roentgens per inspection may be received by the "patient." In addition, the unit operator may receive about 0.1 roentgen to the head and shoulders for each 50 persons inspected (11).

It has been reported (45) that during the manufacture, testing, and operation of high-voltage electronic tubes measurable amounts of potentially harmful X-rays were produced. In one industrial situation studied the exposure to the operator was found to be as high as 2.5 roentgens per day (45).

Theater- or projection-type television tubes have also been reported as sources of X-radiation.

D. Commercial use of X-ray

In the use of fluoroscopy in shoe-fitting, mean exposures from 7 to 14 roentgens per 20 second exposure (an average setting) have been reported (41 (42 (43). Although exposure is intended for the feet of the customer only, dosages of 0.03 to 0.17 roentgen per 20 second exposure have been reported as being received by the pelvis (44). The number of exposures received by shoe customers is not known. It is estimated that the 30,000 to 40,000 persons (shoe salesmen, clerks, and bystanders) are exposed chronically in the operation of the some 10,000 shoe-fitting fluoroscopes in the United States (42) (43).

E. X-ray in research

With the development of atomic and nuclear physics, high voltage X-ray machines have become familiar features of the average laboratory found at universities and similar institutions.

Few data are available as to the levels of exposure received by personnel in such radiation laboratories. Injuries have probably been held to a minimum by frequent turnover of personnel under university laboratory conditions. However, in such laboratories where cyclotrons, linear accelerators, and positive ion tubes, as well as high voltage X-ray machines, have been used, it is estimated there has been a frequency rate of 1 palpable injury per 20–30 man-years of active employment in radiation work (46).

There are about 1,500 X-ray diffraction units in the United States (40). Radiological Health Branch surveys of these units have recorded intensities of scattered radiation up to 1 roentgen per hour (14). There have been several reports of skin ulcers resulting from accidental overexposures in the use of this type equipment (39).

Many research laboratories today use the electron microscope. There are approximately 500 in use in the United States. Several authors (47) (48) (49) have presented papers on the exposure associated with radiation from these units. Intensities of scattered radiation ranging up to 1.5 roentgens per hour have been reported (47).

F. Radioisotopes (excluding radium)

More than 900 universities, hospitals, and research laboratories in the United States have or are using radioactive isotopes produced by the United States Atomic Energy Commission for medical, biological, industrial, agricultural, and scientific research and medical diagnosis and treatment (50) (53).

In a survey (51) of the available radiobiological research and training facilities throughout the United States and Canada, of 153 institutions covered, more than 1,300 staff members and 800 graduate students were engaged in work with isotopes. In 76 of the institutions, isotopes were being used in patients for research, diagnosis, and therapy. It has been estimated that a total of some 7,500 persons are currently engaged in work utilizing radioisotopes in the United States (52).

Of the users of radioisotopes, on the average, about 1 in 300 exceeds the present day maximum permissible radiation exposure (0.3 roentgen per week) and 50 to 75 percent receive less than 0.05 roentgen per week.

During 1950, an average of 45 curies of radioactive isotopes were distributed per month (52).

1. *Medical.*—Radioisotopes are used medically for diagnosis and therapy. Patients to whom these radioisotopes are internally administered may receive 10 or more roentgens whole body exposure from diagnostic doses and from 75 to 100 roentgens from therapeutic doses (54). Single organs such as the thyroid gland may receive from 10,00 to 300,000 roentgens total tissue dosage (55).

It has been recommended as a public health precaution that "patients who receive large doses f I^{131} or Au^{198} should be hospitalized until the total residual activity in the body is not over 30 millicuries" (56).

Radioisotopes are also used in medical therapy as external sources of radiation. Beta ray applicators are available for the treatment of certain eye conditions. Cobalt 60 sources are available in the form of large shielded concentrated

sources for deep therapy and in the form of small needle sources for intracavitary and interstitial therapy.

2. *Industry.*—Cobalt 60 is being used industrially for radiography. There are currently about 80 sources being used in the United States in such industries as railroads, steel, boiler, automotive, ceramics, pressure vessels, and castings (57). The intensity of radiation from 1 curie of unshielded cobalt 60 at 1 foot distance is 14.4 roentgens per hour (50). The quantities used in industry range from one or two hundred millicuries up to as high perhaps as 1 curie (58).

Thickness gages, using radioisotopes, are becoming more and more popular in industry. There are more than 50 utilizing strontium 90 and some 20 utilizing other radioisotopes presently in use in the United States (60). Surveys have shown that the external radiation to which personnel working around the units are exposed is well below permissible limits (61).

Strontium 90 is also being used as a source of ionizing radiation in luminous paint.

These and other radioisotopes are also being widely used in a variety of industrial research problems.

Wastes: Wastes from the use of radioisotopes in industry, the medical profession, and research laboratories, could cause radiation exposure to persons outside the installations using the radioisotopes. Safe disposition procedures have been well covered in official publications (62) (63). Estimates as to the adequacy of disposition methods presently in practice vary (64) (65).

G. Radium

The radiation from 1 curie of radium, inequilibrium with its decay products, and enclosed in 0.5 mm. of platinum, will produce a gamma ray exposure of about 9 roentgens per hour at a distance of 1 foot (66).

1. *Medical.*—In the medical use of radium, the technician, therapist, patient, and persons near the patient (other patients, nurses, and attendants) are exposed.

Since radium seldom can be applied to the patient remotely with accuracy, radium technicians and therapists often receive relatively large exposures. It has been reported in England that the local exposure to their hands in many cases exceeds 1 roentgen per day (67). Other exposure occurs in the preparation and handling of radon capillaries.

It has been reported that the average daily exposure in a typical teleradium installation in England ranged between 0.13 and 0.25 roentgen (68).

In radium therapy, patients receive radiation dosages comparable to those given in X-ray therapy.

2. *Industry.*—(*a*) Radiography: In 1948, approximately 50 grams of radium were being used for radiography in the United States (69). During World War II, this figure reached 100 grams (69), largely due to the fact that X-ray units were difficult to obtain. At present, much of the radium-radiographic work that was done during the war has been discontinued and X-ray machines and cobalt-60 are being used instead.

Radium sources are commercially available in 25, 50, 100, 200, 300, and 500 milligram units. The 100 and 200 milligram sources are most commonly used (69).

Average exposures received by industrial personnel handling radium are not known.

(*b*) Luminous compounds: Several hundred grams of radium were utilized in the luminous compound industry in the United States during World War II (73). During this period there were several thousand workers engaged in the use of self-luminous paints. After World War II, the number decreased and in 1948 there were only about 300 people engaged in this work in the United States (69).

Although individual workers handle only small quantities of radium daily, the hazards to health from this use of radium are significantly greater because it is not sealed in a container and, therefore, can be ingested or inhaled.

Under present conditions, it is recommended that no worker exceed a maximum permissible amount of 0.1 microgram radium fixed in the body (70). Under the best working conditions existing in 1943 in the radium dial painting industry, 15 percent of the workers accumulated more than the maximum permissible amount (71). It has been reported (72) recently that a survey in a military-aircraft-instrument shop, which followed the safety regulations of the National Bureau of Standards, found a degree of radium contamination greatly in excess of the maximum permitted.

It is generally accepted that the maximum allowable level for radon in the air is 10 micromicrocuries per liter (46). It has been reported that when workroom ventilation requirements are met, the radon concentration in the workroom air will not exceed 80 percent of the maximum permissible limit (71). However, ventilation requirements are not always met, especially in storage and packing rooms and offices.

The normal gamma radiation exposure received by dial painting workers appears to be about 0.02 roentgen per day (46).

Exposures may also occur in the use of the finished product to which a luminous compound has been added. A watch may have approximately 1 microgram of radium on it. Some clocks and aircraft instruments may contain from 10 to 100 micrograms of radium (74). It has been reported (74) in surveys in airplanes that the level of exposure at the instrument panel was 0.01 roentgen per hour and from 0.0002 to 0.001 roentgen per hour at the pilot's body position.

(*c*) Reprocessing and preparation of radium and radon sources: Radium preparations that have become obsolete in either design, or use, or the seal of which has broken or worn thin, should be reprocessed. This work involves hazards similar to those encountered in the subdivision of radium into capsules for medical or industrial use. The work is performed by relatively few companies. However, the work has not been governed by general regulations of the type applied to the luminous compound industry. A radon concentration of 2,200 micromicrocuries has been quoted as average in the general laboratory of one of the most reputable companies (46).

The operation of radon plants, commercially or in hospitals, can be very hazardous since the worker is exposed not only to radon but also to beta and gamma radiations of the radium and its decay products.

(*d*) Static eliminators: Static eliminators are widely used in textile and paper trades, in printing and photographic processing industries, and by telephone and telegraph companies.

One type, the ionotron, consists of a bar containing a strip of metal impregnated with radium. A thin layer of gold and nickel are plated over the radium-metal strip to protect the radium and act as a seal.

The main hazards from the ionotron are exposure to beta and gamma radiation (alpha constitutes little external hazard) and radon gas.

Actual exposures of 0.003 to 0.005 roentgen per hour for pressmen and 0.5 to 1.0 roentgen per hour for maintenance personnel have been reported in a survey of a printing plant (75). Fortunately the latter duties required only about 15 minutes per day of such exposure.

In other surveys, levels up to 0.085 roentgen per hour have been reported in the working area near such units (69).

The radon hazard from ionotrons is small, if they are given proper care. However, if the seal is broken, a radon hazard may result. Several surveys have pointed out that improper storage and handling of static eliminators is common (76).

A second type of static eliminator, the alphatron, contains polonium as the radioactive source. These units constitute little external radiation hazard since the alpha particles from polonium travel only a short distance in air. The hazards associated with their use result primarily from ingestion or inhalation of polonium liberated through breaking of the gold seal and flaking (77).

Polonium will volatilize at lower temperatures than radium and careful consideration must be given this point in certain specialized applications (77).

Static eliminators are also used with analytical balances and microtomes.

Polonium bars are also mounted on brushes for use as a static charge eliminator for phonograph records and photographic films.

Lost radium: Numerous instances of radium being lost have been reported in the newspapers. Taft (78) has reported on 107 losses with 59 complete recoveries, 11 partial recoveries, 36 total losses, and 1 unknown result. There is danger of unsuspected radiation exposure in all such instances.

Shipping of radioactive materials: Exposures can occur during the handling and shipping of radioactive materials. Interstate Commerce Commission and Post Office Department regulations governing the shipment of radioactive materials by domestic ground and water transport and the interim regulations for shipments by air attempt to accomplish three objectives:

(1) protection of people,
(2) protection of film,
(3) avoidance of excessive shielding weight (excessive carrying charges).

It has been reported that the maximum exposure which an airplane crew member or passenger would receive under the regulations would be 0.012 roentgens per hour. Maximum exposure for pilots (flying 85 hours per month) would then be 1.02 roentgens per month (74).

H. Nuclear reactors

A "water boiler" (79) type nuclear reactor is being built at the North Carolina State College. Data on this reactor can serve as a tentative guide in establishing the importance of such installations with regard to the radiation levels in the United States.

The North Carolina reactor is to operate at a maximum of 10 kw. Heavy shielding will limit the exposure, resulting from a maximum of some 105 curies of activity present, to a safe level.

The heat generated during operations will be removed by circulating water through sets of cooling coils inside the reactor cylinder. This water, from the Raleigh city system, will be fed into the reactor after passage through automatic pressure reducing-regulating valves; at 10 kw. power level a total of 3 gallons per minute will be required.

The intense neutron bombardment received by the coolant in passing through the reactor will induce radioactiivty in it (principally in the dissolved and suspended solids). The resultant activity will be near 1,000 disintegrations per second per cubic centimeter initially. Assuming no shielding and no internal absorption of radiation by the water, 10 gallons of freshly irradiated water would produce a radation dosage rate of approximately 0.08 rotentgen per 8 hours a distance of 5 feet. After 1 hour, the dosage rate would drop to about 0.0008 roentgen per 8 hours at a distance of 5 feet. Tanks for collecting and retaining this waste water for 10 hours are provided.

The reactor in operation produces a small volume of gaseous fission products, resulting from the fission of uranium into elements of gaseous nature, and larger volumes of other gases resulting from the decomposition of the water molecules in the fuel solution into hydrogen and oxygen. The activity of the fission product bases will be considerable, amounting initially to about 7,000 curies per kilowatt-minute.. However, after 4 hours, the 7,000 curies will have decayed to 0.15 curies. The activity of the decomposition gases will be negligible. At 5 kilowatt operating level, the total volume of gases produced will be 40 liters per hour. Solid as well as other liquid and gaseous wastes will result if laboratory or experimental programs are conducted in conjunction with operation of the reactor.

It has been reported that at least five major universities have expressed interest in following the steps of North Carolina State College by building research reactors outside of Atomic Energy Commission sites (81). Undoubtedly, other reactors will soon be built at other colleges and universities and in industry.

A second type reactor is being built by North American Aviation, Inc., in California (80). It too should serve as a guide in establishing the importance of such installations in the total radiation exposure in the United States. The reactor is to be of the enriched-uranium, graphite-moderated, type and will be used for research. It will be operated at a designed capacity of 160 kilowatts and will be shielded by 6 inches of steel and about 3 feet of "heavy" concrete (total weight 450 tons). Data as to the wastes to be produced by this reactor and resulting radiation exposures have not been released.

I. Particle accelerators

In 1941, there were only some 16 cyclotron laboratories in the United States (12). It was reported that due to the tremendous cost of particle accelerator units (namely cyclotrons, synchrotrons, Van de Graaff generators, and betatrons), their number was not apt to grow to more than a few dozen (82). However, the impetus to nuclear research created by the atomic energy program has caused their number to increase to over 100.

For example, 20 machines came into operation in 1950 and 21 in 1951 under auspices of the Atomic Energy Commission (83). One company reported, in a recent advertisement, that it had built 15 Van de Graaff Electrostatic Accelerators at research installations in the United States (84).

Exact determination of the type and intensity of radiation encountered around particle accelerators is often difficult or impossible because of the mixture of radiations present (85). Beta radiation originates from the various accelerators but the possibility of direct exposure is slight (85). Neutrons probably constitute one of the main hazards as they are produced in profusion in the operation of cyclotrons and synchrotrons (82).

Impaired vision of several nuclear physicists as a result of work with cyclotrons was reported recently (86). The general injury rate for laboratory radiation workers was discussed under the portion of this paper covering "X-Ray in Research."

J. AEC activities

Activities of the Atomic Energy Commission in the fields of fissionable material production and weapons testing contribute to the level of radiation to which special groups and the general public are subjected. Specific items are:

1. *Uranium mining and milling.*—The uranium mining and milling activities in this country are predominantly restricted to the region of the Colorado Plateau. Some 2,000 miners and millers are engaged in this work (87). It has been reported that the mining and processing of the ores and metals yield dusts and fumes which are sources of radioactive air pollutants (88). The United States Public Health Service and several State agencies are active in studies of the specific hazards in this industry (89). They have reported finding radon exposures above the maximum permissible limit in several of the mines. In these instances, control measures are being applied as rapidly as possible.

2. *Operation of nuclear reactors.*—Operation of nuclear reactors within the Atomic Energy Commission contribute to the magnitude of the radiation exposure in the United States. It has been reported that the use of air for cooling purposes in nuclear reactors is a source of radioactive air pollutants (88). The use of water for cooling purposes at Hanford contributes radioactivity to the Columbia River.

3. *Other AEC plant wastes.*—Chemical dissolving and separation processes and the operation of "hot" laboratory hoods plus the incineration of contaminated solid materials (such as experimental animals) are all sources of radioactive air pollutants (88).

Since the operations producing these radioactive air pollutants are widespread, the potential hazards are by no means always confined to those directly employed in such activities. The discharge of radioactive gases, dusts, and other radioactive pollutants outside the immediate area of operation may greatly increase the radius of the possible health hazards (90).

The chemical dissolving and separation processes also contribute liquid wastes. It has been reported that the Oak Ridge installation of the AEC discharges up to 5 curies per day of liquid wastes (91).

4. *Weapons tests.*—In 1951 12 bombs were dentonated at the AEC Proving Ground in Nevada.

The fission product activity 1 hour after the dentonation of a nominal atomic bomb is in order of 10^9 curies. One week later, there are still about 10^7 curies remaining (92). Fortunately the majority of this activity probably remains in the upper atmosphere. However, some of it is distributed over most all of the United States. For example:

(*a*) Radioactive snow has been reported falling over wide portions of the United States following these tests (93).

(*b*) The background count in many radiation laboratories increases by a factor of 5 to 10 during these periods, necessitating in many instances the curtailment or complete stopping of counting activities.

(*c*) Film manufacturing companies must take precautions to prevent fogging of their film during these tests (94). In the 11th semiannual report of the AEC, it was stated that the photographic industry must specially treat water used during these periods due to contamination from fallout (83).

K. Other factors affecting exposure levels

1. *Availability of radioactive materials.*—Under the law, the Atomic Energy Commission carefully controls the distribution of radioactive materials produced in its operations. However, naturally radioactive materials are not subject to similar regulations. As a result, certain products containing small quantities of naturally radioactive materials may be purchased on the open market. For example, brushes for use as static charge eliminators (polonium), and instruments with luminous dials (radium). The high cost of large quantities of radium (such as are used for industrial radiography and medical therapy) and the care exercised by the radium companies in their distribution tend to eliminate them from the "open market" classification.

2. *Fission products.*—Only about 4 curies of fission products had been distributed by the Atomic Energy Commission through 1950; the rate of distri-

bution is expected to increase considerably within the next few years. Suggested uses for fission products include:

(a) Activation of phosphors.
(b) Static eliminators.
(c) Fluorescent light tubes.
(d) Instruments containing radiation sources.
(e) Industrial radiography.
(f) Cold sterilization of food and drugs.

L. Accidents

Accidents appear to be an implicit complication of all activities involving man. There is no reason to believe that his activities in the radiation field will differ in this respect. In fact, numerous instances of radiation injury have been recorded in the literature (39) (86) (97) (98) (99). In addition, based on private conversations, it is believed that only a small fraction of the accidents which do occur are ever recorded in the literature.

Any radiation exposure from accidents would be in addition to the exposures listed elsewhere in this article. Obviously, the potential amount of exposure and the probable severity of injury incurred in an accident would vary with the amount of radiation involved.

IV. COMMENTARY

A summary of the published literature available to the Radiological Health Branch and pertaining to the sources and levels of radiation exposure in the United States has been presented.

Definite conclusions concerning the relative public-health importance of the several categories of radiation sources in the United States should not be drawn from the data presented since the amount of the published literature in each field largely determined the data available.

The public-health importance of individual sources will vary for different localities. Furthermore, this relationship is constantly changing. For example, many radiation-minded health people feel that, in the future, use of nuclear reactors in research, medicine, and industry will be the biggest public-health problem.

This paper is intended to serve as a guide to the State and local health officer in seeking out, evaluating, and controlling the radiation affecting the public health in his area. If it is of assistance in initiating a radiological public-health program at the local level, it will have served its purpose.

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The committee will stand in recess.

(Whereupon, at 12:30 p. m., the committee recessed, to reconvene at 2 p. m., of the same day.)

AFTERNOON SESSION

Representative HOLIFIELD. The committee will be in order.

There will be a slight change in order of the witnesses by agreement. We will ask Dr. Western to be the first witness. Dr. Forrest Western of the Division of Biology and Medicine of the Atomic Energy Commission will be speaking on the subject of delayed fallout, the behavior in geological and physical processes and the mechanisms by which delayed fallout enters into the biological processes and reaches man.

Dr. Western, we are happy to have you with us.

STATEMENT OF DR. H. L. FRIEDELL, SCHOOL OF MEDICINE, WESTERN RESERVE UNIVERSITY [1]

Dr. FRIEDELL. Thank you, sir.

Mr. Chairman, and members of the joint committee, and ladies and gentlemen, I have the unenviable task of trying to introduce an exceedingly difficult and complex subject. We have gathered information on the whole problem of radiation, and the biological effects of radiation, essentially within the past 20 years, and I think it takes a little while before this matures so we can undertstand it fully. Nevertheless, I think there is a place for orientation here for examining some of the basic concepts of what we do know about radiation, about trying to separate various kinds of effects one from the other, when radiation is administered to a biological system. I would like to briefly introduce this.

Time is limited, but I think the others will very readily fill in any hiatuses that exist. There are many none of us can fill in, I think. They will augment wherever necessary the things I talk about.

Representative HOLIFIELD. While we are trying to keep to the schedule, we are not going to cut any witness short. We may ask for documentation, and if you have something that you feel the committee should know, you may proceed to give it.

Dr. FRIEDELL. I think we will want to take a look at how radiation introduces the biological effect, and then we will try to separate some of the things that occur.

It is interesting that radiation we cannot see, hear, feel, or smell, will initiate very profound effects, the way it appears to do this is by this radiation interacting primarily with the atoms that comprise the biological molecules.

The way they interact with the atoms is, in essence, interaction with their electron shells. Most of the physical changes involve these electron orbits, but there are some others which do occur which are essentially insignificant in the broad overall picture.

Specifically, an ionizing particle or powerful photon, a piece of electromagnetic radiation, will come in and pull away an electron out of the atom. Once it has done this, it has now disturbed the atom, made it into an ion, and this ionized atom and the electron will form an ion pair—or it may move the electron into a different energy level. Then it is excited, and may then concern itself with various chemical and biochemical reactions.

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[1] Professional background: University of Minnesota, M. D., 1936; University of Minnesota, Ph. D., 1939; National Cancer Institute Fellow; Chicago Tumor Institute, 1939–40; Memorial Hospital, New York, 1940–41; University of California, 1941–42; instructor in radiology, University of California, 1941–42; United States Army, lieutenant colonel, 1942–46; executive officer and Deputy Chief, Medical Division, Manhattan District. Present work: Professor of radiology, Western Reserve University; director, department of radiology, University Hospitals of Cleveland; director, Atomic Energy Medical Research project, Western Reserve University. Committee appointments: Veterans' Administration, Central Advisory Committee, Radioisotope Section, Reserve and Education Service; National Research Council, Subcommittee on Radiobiology; Atomic Energy Commission, Advisory Committee on Reactor Safeguards; National Bureau of Standards, Subcommittee on Permissible External Dose; State of Ohio, advisory committee on atomic energy. Member; American College of Radiology, American Medical Association, American Radium Society, Association for Advancement of Science, Association of University Radiologists, American Roentgen Ray Society, Radiological Society of North America, Society of Experimental Biology and Medicine, Radiation Research Society, Sigma Xi, Alpha Omega Alpha. (Submitted by witness.)

When this occurs it is obvious immediately that the molecule that is then so vital and important to the cell has been disrupted or disturbed and many things can happen to this molecule.

It is of interest to observe that a cell has roughly 10 to the 14th molecules, and a thousand roentgens, a dose which generally is lethal, will affect only about 10 to the seventh molecules. In other words, one ten-millionth of these are affected, and yet this single injury to an atom or molecule among these many will introduce violent and very serious biological effects. The physical effects are over generally in a very short period of time. Immediately thereafter the disrupted molecules become involved in various kinds of chemical and biochemical changes. And again these are over in a few microseconds. So that the process of the physical effects and the biochemical effects are finished within a very, very short period of time, and yet we observe the biological effect in hours, days, months, and possibly even years later. This is an important concept to retain and keep in mind.

Representative HOLIFIELD. This statement is based on experiments with animals?

Dr. FRIEDELL. These are based on experiments primarily in vitro; in other words, studying tissues or systems outside of complex animal, because it would be very difficult to observe it in an animal itself. From the point of view of the occurrence of biological effects, these are observed in animals—correct.

Representative HOLIFIELD. And is applicable to man?

Dr. FRIEDELL. And is applicable to man.

Representative VAN ZANDT. Dr. Friedell, at this point, do you have information concerning the animals that were exposed to radiation in the Mariannas in the 1954 tests?

Dr. FRIEDELL. I am aware of it. I am not entirely familiar with it.

Representative VAN ZANDT. In other words, the Mariannas tests are not involved in your presentation?

Dr. FRIEDELL. I would say what I am going to present would be involved in all biological effects of radiation. These are the basic things that occur at the beginning. They really are the initial things, and I want to proceed much further in developing this.

Once we get the injury at the chemical and biochemical level, obviously the first unit that may be injured is the cell, and all organisms are comprised of cells, as we know, and are complex organizations of cells. We, therefore, can perhaps begin, once we take a look at this matter, to look at the cells themselves and see what kind of biological effects occur here.

Before I go on to the cell, I would like to make this point: Undoubtedly many of you are familiar with the effects of protecting cells with various chemical and biochemical agents. The way this has been done, in effect, is to take a look at some of the biochemical changes that might occur in a system, and see if it would be possible to prevent them or counteract them. Specifically, we might think briefly of a system that can be affected easily and studied readily, and that is the disruption of the water molecules.

Water is an abundant material in biological systems—ordinary biological systems. This water molecule will undergo exactly the same changes that any vital complex molecule might undergo in the cell itself, because the ionization makes no distinction between these. As-

suming roughly the same conditions, it will ionize water just as well as it will ionize anything else. And if you ionize the water, tear it apart, you now produce radicals, so to speak, which will either reunite or will be modified in some other way.

If oxygen is present, which is another very important element, and present in the biological system, they may combine with oxygen to make very powerful oxidizing agents.

It is presumed at levels we talk about, up to several thousand roentgens, that this effect, which is considered an indirect effect (in other words, producing ionization and modifications of the atoms that may not be directly involved in the biological systems, such as water), in turn produces serious effects, because they become noxious radicals, so to speak. They become oxidants, highly powerful oxidizing agents, and may, in the presence of very vital atoms or molecules, alter them and, in turn, produce these serious biological effects.

Therefore, if you were going to attempt biochemical repair of this, or chemical repair of this, you would either prevent the oxidation from producing radicals, or you might introduce something that is an oxygen acceptor, a reducing agent so to speak, and therefore either spare the effect on the molecules or in some way interfere with this occurring.

One of the common compounds we know fairly well is cysteine, which has sulfhydral groups. We do not need to go into the chemistry and exact nature of these things, but they will accept oxygen, and if you introduce enough of these into the cell, these will, in effect, either combine with the noxious radicals to start with, or by the statistical process of dilution prevent some of the vital cell molecules from being affected.

So that this is one attack that has been made in altering or in preventing this biochemical change from occurring and, therefore, being seriously damaging to the cell.

I said earlier that oxygen needed to be present in order for a large number of these oxidizing radicals to be produced, and this is another way in which we can protect the cell. You can reduce the amount of oxygen. You can either limit the amount of oxygen physically by putting the organisms in oxygen-free atmosphere, or by making some physiological change so that the oxygen is low in vital areas of the cell. When you do this you also protect the organism.

So that our beginning knowledge about the biochemical effects are extremely important in giving us an understanding how biological effects will occur, and how we might modify them in the biological system.

Representative HOLIFIELD. Does that have any practical effect on radiation sickness?

Dr. FRIEDELL. Unfortunately, its practical effect is rather small, for this reason: These things must be done immediately before the radiation is delivered, or at the time the radiation is delivered. Unfortunately, if it is done after the radiation is delivered, this, of course, is no longer effective because all of these things we are talking about would have occurred already.

Representative HOLIFIELD. So this is an interesting scientific fact, but from the standpoint of protecting the people from radiation it is inapplicable?

Dr. FRIEDELL. Essentially and practically inapplicable, but it is important in understanding the mechanisms that occur.

I think it would be well to then begin to take a look at what happens in the cell itself, and the people after me are going to talk about this, and extend some of the basic concepts further. But I believe it would be useful to look at the cells and see what we know about them from a radiological point of view.

We have for a long time studied the various responses of cells to radiation, and have made up a little chart which tells us something about how sensitive these are to radiation, and how easily affected they are by radiation. It is important to understand this because, if you are going to understand what happens to the whole organism, you must obviously know how dependent the whole organism is on the economy of any single cell and how easily this is affected by radiation.

I would like to read this to you from the statement that will be introduced in the record. I will read a list of cells I have made up and listed as extremely sensitive, highly sensitive to moderately sensitive, and insensitive.

The basic cells of the hematopoietic system—lymphocytes, erythroblasts, myeloblasts—closely associated, are extremely sensitive to radiation, and small doses will injure these cells severely.

In the same category, I would include the germinal cells of ovary and the germinal cells of testis. As far as our purposes, I would consider these as highly sensitive, and very readily and quickly affected by radiation.

Mr. RAMEY. When you use the word "lymphocyte" what would be the common name for that?

Dr. FRIEDELL. I would guess that you call these the germinal cells in lymphatic tissues, such as lymph nodes and other tissues that are related to lymph nodes. These also possibly have their origin in the hemotopoietic tissue as well. In other words, the blood-forming organs as well. Perhaps that is what you were referring to.

The next group, which is a little less sensitive—and I would consider these as moderately sensitive to possibly highly sensitive—would be the epithelium of intestinal crypts lining the insides of the intestines, and certain basal layers that originate in the epidermis.

These basal layers of the epidermis and the epithelium of the intestinal crypts, I would say, would be less sensitive, but nevertheless easily affected by radiation.

Now, there are a group of cells which seem to be unaffected except by extremely large doses. I would like to say that all cells can be affected by radiation; if you introduce enough energy, transfer enough energy to the vital systems of the cell, you can destroy them all. But some of the cells require very large doses. Generally the way we look at this is that cells that are highly active and rapidly dividing seem to be affected by radiation more easily than those that are slower growing and more highly differentiated in the sense they are more highly specialized.

These latter seem to be affected by radiation less. I would include in these things like muscles, bone cells proper, liver cells, brain cells, nerve cells, kidney cells. And ordinarily, when lethal doses of radiation are given to the organisms, we will find that these cells are essentially unaffected. You can find no important change in the cells proper.

Now, if you begin to accept this—and it is somewhat difficult to digest without studying it a little bit—you can then begin to understand what happens to organisms as a whole when the organism receives large doses of radiation.

First of all, we can see that certain tissues are going to be promptly injured, and these tissues are going to be the blood-forming cells, such as the leukocytes, and the gastrointestinal cells. Most of the others will be unaffected.

If the organism is vitally dependent on the cells, it will be fatally injured. If it is not vitally dependent upon these cells, there may be modifications, but the organisms proper may not be injured. Therefore, we can begin to understand how we can injure certain cells and yet not affect the organisms seriously.

For example, you can give a fair dose of radiation, which might kill the organisms, to the liver cells alone, and yet the organisms will not die. You can give this kind of radiation to the muscle cells, for example, and the organisms will not die. On the other hand, if you deliver this radiation to the hemotopoietic system, the blood-forming tissue, the organism will die because these blood-forming organs are very vital to the cell.

One of the important things involved is defense against infection. That is, the white cells of the blood-forming organs are very important against infection, and, therefore, reducing the cells would seriously affect the organism and various kinds of infections would rapidly take over.

Representative HOLIFIELD. There is an old saying that a chain is only as strong as its weakest link.

Dr. FRIEDELL. Correct.

Representative HOLIFIELD. When we are talking about the effects of radiation on the human body, and the life span, we must of necessity address our remarks principally to the weakest link in evaluation of the radiation.

Dr. FRIEDELL. Right.

Representative HOLIFIELD. It is of small comfort to know that one section of the body is not so badly affected by radiation, if in the meantime another section of the body which is vital to existence has been destroyed.

I am not saying we should not know this, but I am saying the important thing is to evaluate its effect upon that weakest link in the life cell, the reproductive chain.

Dr. FRIEDELL. This is very true, and when we speak of total body radiation, in other words, when we irradiate the whole organism, then obviously we have to examine the weakest link, and the weakest link would be the hemotopoietic system, and the gastrointestinal tract.

However, when you deal with radio elements, they have certain preferential deposition, so to speak, and therefore, in order to orient yourself, you must understand that certain radio elements that may be administered to an individual will deposit themselves preferentially in one area and, therefore, will essentially have no effect on the gross economy of the individual.

One of the examples I can cite to you is the use of modest doses of radioiodine.

In the adult, the thyroid is a relative insensitive organ, and you can deliver doses to the thyroid in the order of 500 roentgens which

will to all intents and purposes produce no demonstrable effect. On the other hand if you gave 500 roentgens to the total body, or to a very vital structure, you would injury the animal perhaps fatally. This is the reason I introduce this.

Representative HOLIFIELD. By the same token, radio isotopes such as strontium 90, which have been deposited directly into the bone structure and goes right on shooting the powerful rays into the cells around it, would be more damaging than the comparable amount of radiation that was external to the body, would it not?

Dr. FRIEDELL. That is essentially correct. Of course, now we come to one point which is included on our outline—How do we make a decision as to whether certain radio elements are likely to be injurious, and how do we separate radiation coming from radioactive elements or radiation coming from cosmic rays or X-ray machines?

I would like to say this: That all particles or photons (electromagnetic radiation) which are energetic enough to produce ionization will produce the same kind of biological effects, roughly. There are modest differences, but in essence they would produce the same kind of biological effects.

How do we compare radio strontium, for example, with X-rays, or one radio element to another. Let's look at that first.

First of all, the half life of the element is very important. Will it last? Will it radiate a long period of time?—because this is going to determine what the dose is.

Another very important item is how energetic is this particle, and what is the range of this particle. This is tied in with its energy. So we have to know whether it is long lived, what kind of particle it produces, how energetic it is, what is its deposition in the body, will it deposit in vital areas or will it not deposit in vital areas.

These are the kinds of things we have to look at and examine in making any decision about whether a radio element will be serious or not.

Now, strontium 90 happens to fit some of these categories because it is a very long-lived material, and it deposits itself in areas which are vital to the economy of the organism.

Representative HOLIFIELD. Would it be inclined to deposit itself in concentrated areas in the bone, or diffuse through the bone structure?

Dr. FRIEDELL. It appears that strontium 90 is chemically very much like calcium. Therefore, as a good first approximation, we would assume, and I think reasonably conclude, that it distributes itself as calcium does in the bone, which is widely throughout the bone.

Representative HOLIFIELD. But in the case of a broken bone, for instance, that was being repaired, the tendency would be for it to concentrate during the repairing——

Dr. FRIEDELL. During the process of healing, we know there is more calcium deposited at the site of fracture, and, therefore, more strontium 90 would be deposited at the site of fracture.

Representative HOLIFIELD. We hear of bone cancer. Does that take place as a result of bombardment of strontium 90? Does that take place throughout the bone, or is it localized in certain areas of the bone, in the marrow, for instance?

Dr. FRIEDELL. Strontium 90, after you once introduce strontium 90 or, for that matter, almost any element that will seek the bone—and

we have gotten to use the term "bone seeker"—this will distribute itself more or less throughout the bones. Some have special depositions, but it is also the long continued radiation which does the damage. Therefore, it is a question of dose. There is evidence that no matter what radio element you use, if it is a bone seeker, and if it will radiate long enough to give a high enough dose, you will produce bone cancers—at high enough levels. That is what I would like to emphasize.

Senator HICKENLOOPER. Mr. Chairman?

Representative HOLIFIELD. Senator Hickenlooper.

Senator HICKENLOOPER. Doctor, is bone cancer a new thing?

Dr. FRIEDELL. Is it a good thing?

Senator HICKENLOOPER. A new thing.

Dr. FRIEDELL. No, sir.

Senator HICKENLOOPER. Is it something recently discovered?

Dr. FRIEDELL. No, sir.

Senator HICKENLOOPER. Have we not had bone cancer——

Dr. FRIEDELL. Bone cancer has been known almost since time immemorial.

Senator HICKENLOOPER. As long as we have had real medical knowledge?

Dr. FRIEDELL. I think so.

Senator HICKENLOOPER. Bone cancer occurred before we ever had any atomic tests or explosions, did it not?

Dr. FRIEDELL. Yes, it did.

Senator HICKENLOOPER. What would have caused bone cancer many years ago? Is that the absorption of certain nuclear particles, or does it come from some unknown activity of the cells as a starter?

Dr. FRIEDELL. I personally would hesitate to attribute this to the absorption of previous radiation or previous nuclear particles before we began the fallout tests. I think that on the whole this is related to some special biological factor that is yet unknown, and I hope we will hear a little later from one of the other witnesses about some of these special things that might contribute to the production of cancer in general.

Senator HICKENLOOPER. Yes. I mean we have heard a great deal about bone cancer since there has been some radiation released through bomb explosions, but I just wanted to at least assure myself that my belief was right that we had had bone cancer from time immemorial.

Dr. FRIEDELL. Yes, that is true. I will be glad to insert in the record the assertion that bone cancer has been present long before the tests began.

Representative HOLIFIELD. Our concern with strontium 90, though, is that it is an artificial element that is created by thermonuclear explosions and atomic explosions, and it is now a new factor, an additive factor, and experiments have proven that this new element which has been introduced is a cause of bone cancer. That is our concern, is it not?

Dr. FRIEDELL. This is true. But I think there is one very important point we have to look at very hard. That is, what are the levels of radiation? And what evidence do we have that these levels of radiation have produced bone cancer? And what are the bases for

assertions by some that bone cancers will be produced at very low levels in a small percentage of people?

Perhaps later, if I do not forget—I would be glad to be reminded of this—I would offer my humble opinion of this, because I have been looking at this as a radiologist for a number of years, and I am interested in this whole problem.

Representative HOLIFIELD. Why do you not discuss it now? We are on the question now.

Senator BRICKER. May I ask one question before he goes into that?

Representative HOLIFIELD. Yes.

Senator BRICKER. We know that radiation has a tendency to prevent the development of cancer in certain organs?

Dr. FRIEDELL. Yes, sir.

Senator BRICKER. And it is used for that purpose. Would there be any beneficial radiation that might come from strontium 90?

Dr. FRIEDELL. I would say that no radiation is for preventive purposes. I think radiation is used for curative purposes.

Senator BRICKER. For curative, palliative purposes.

Dr. FRIEDELL. Yes, sir.

Senator BRICKER. Would there be any of that effect come from ingested strontium 90?

Dr. FRIEDELL. I could see no benefit that might arise from deposition of radioactive elements.

Senator BRICKER. I have never heard it intimated, but I do know that radiation has been used in the cure of cancer, to help palliate the pain and prevent the growth.

Dr. FRIEDELL. Yes, sir. But in normal tissues I would be opposed, as a matter of fact, to the introduction of radioactive elements as a possible preventive measure.

Senator BRICKER. Of course, we all would. I would not want to take a chance. I wondered if there was any thinking along this line.

Dr. FRIEDELL. No, sir; I do not know of any.

Senator BRICKER. You have not heard it suggested.

Senator HICKENLOOPER. Mr. Chairman, along that line, I would ask one other question, if I may. That is along the line Senator Bricker is discussing.

Could there be any beneficial effect possibly flowing from the introduction of some of these radioactive elements, so far as a cancer that was in the process of formation, or growth within the system which came from other than causes which might have resulted from radiation?

Mr. FRIEDELL. I would say "No."

First of all, the levels of radiation—and again I want to emphasize this: We are talking about entirely different levels. To give you some idea of what the levels are to be curative in the case of cancer (incidentally bone cancer is an extremely resistant form of cancer, and radiation even in large doses is essentially ineffective), the doses that are necessary to cure cancer are in the order of five to ten thousand roentgens. The doses we are talking about, especially from the fallout levels, are in the thousandths of roentgens. So that we are not talking about the same order of magnitude at all.

Senator ANDERSON. I did not follow you on that.

Senator HICKENLOOPER. I think we have done quite a little experimental work in the radioactive iodine in thyroid, and cancer.

Dr. FRIEDELL. Yes, this is true.

Senator HICKENLOOPER. And at least some other attempted specifics along that line.

Dr. FRIEDELL. Yes, sir. In the case of radioiodine, certain cancers of the thyroid are very beneficially affected.

Representative HOLIFIELD. Mr. Van Zandt.

Senator ANDERSON. I want to clear up one thing first.

When you said from five to ten thousand roentgens, then you said the levels we are using here are "thousands" of roentgens?

Dr. FRIEDELL. "Thousandths." Decimal point zero zero one (0.001).

Senator ANDERSON. That is what I wanted. It was not very clear.

Representative HOLIFIELD. Mr. Van Zandt.

Representative VAN ZANDT. Dr. Friedell, in the event of a fracture with the presence of strontium 90, would the strontium 90 in any way slow down the mending of the bone?

Dr. FRIEDELL. I hesitate to answer that, because I have no specific information. But if I may conjecture, I would say it would be slowed down at very high levels of radiation, far above anything we have considered here. And I do not believe you could establish any difference in the growth rate at the kind of levels that are being talked about from fallout.

Representative VAN ZANDT. Then you cannot state whether a low dose of radiation would have any effect on the mending of the bones?

Dr. FRIEDELL. I would hesitate to propose that. I doubt it.

Representative HOLIFIELD. We recognize, Doctor, you are providing us the background statement, and others will go into these different facets.

Dr. FRIEDELL. Very well.

Representative HOLIFIELD. Will you proceed?

Dr. FRIEDELL. With regard to understanding what happens to the whole organism concerning the radiation syndrome, I think we have to look at what happens to the individual from the point of view of the systems that were injured. We try to point out a very cursory relationship between tissue sensitivity, the kind of effects that would produce, cellular effects where the economy of the organs was dependent upon these; and then we can look at some of the systems and pathological findings that might occur.

Since we know the gastrointestinal tract, and the hemotopoietic system are very sensitive to radiation, we can observe, with fairly large doses of radiation, symptoms and pathological effects that are directly related to these. The hematopoietic effect, of course, will appear as a severe drop in the white cells.

I will not go into the kinds of white cells. There are many more competent in this field than I, but this is generally true.

Some of the basic cells in the hematopoietic system are affected, which in turn affects the production of the platelets, which are tissue components in the blood required for the proper function of the clotting mechanism. These are seriously depleted, and under such circumstances you will get all kinds of bleeding tendencies. An individual who is heavily irradiated will show symptoms associated with the gastrointestinal tract, and with the hematopoietic system more or less simultaneously. In the doses that are high, the patient will become nauseated and vomit because of the immediate effects on the gastrointestinal tract, possibly also because some of the vital large

molecules are disrupted, so to speak, by ionization, which we point out can split some of these things up, and it may be these are circulating about and produce some of these effects.

So that an animal that is immediately irradiated in a very few hours may show nausea, vomiting, anorexia, severe diarrhea. This is directly related to what we can observe in the cells themselves, and in the tissue systems. There will be severe hematopoietic changes (the blood changes).

The organism has now lost its defense against infection, and infections will take over very promptly, and we can begin to observe in obvious areas the oropharynx, respiratory, and gastrointestinal tract, ulcerations and infection as a result of this injury to the tissue.

There will be little bleeding points throughout, as a result of interference with platelet formation. If they go on, the animal will be severely injured, and will die, partly as a result of these intercurrent effects, but also because we are unable to replenish some of the vital cells, or the body itself cannot replenish any of the vital cells.

This brings me to a point which we discuss not infrequently——

Representative HOLIFIELD. You are talking of large doses now?

Dr. FRIEDELL. I am talking of large doses in the order of 500 to 1,000 roentgens delivered to the individual.

This brings us to a point of how we might possibly protect the organism against radiation effects.

If we look at some of the very vital cells, it is reasonable to conclude that if it were possible to get these cells to be repopulated, possibly from an outside source, then the animal might be able to recover if the doses have not been really too large.

The recent efforts in this direction have been to get bone marrow cells introduced into the organism that has been heavily irradiated to see whether these cannot repopulate the hematopoietic system, at least until the cells themselves may have had an opportunity to recover.

Representative HOLIFIELD. This would indicate, from a practical standpoint, that you would have to have a bank of bone marrow cells for introduction into the system.

Dr. FRIEDELL. That is correct.

Representative HOLIFIELD. The same as you have to have a blood bank for transfusions?

Dr. FRIEDELL. This introduces many practical problems, and I am not sure it will have any place at all in attacking this problem.

Representative HOLIFIELD. I think it is important to bring this to the point of practical application, because a great many lay readers might think this could be a remedial measure which could be taken in a practical way. Of course, even transfusions would not be of any permanent lasting good if the spleen was affected.

Dr. FRIEDELL. Yes.

Representative HOLIFIELD. Or other blood producing organs.

Dr. FRIEDELL. Right. Essentially, if blood producing organs are seriously affected, it is doubtful if the transfusions have anything other than a transient effect. Generally, in doses of about 500 roentgens, which is presumed to kill, roughly, about half of the humans that may be affected by such a dose, supportive measures might be helpful, such as transfusions, replacing the fluid that is lost as a result of gastrointestinal injury. The use of antibiotics would be very effective be-

cause they would help to combat the infections occurring while the defenses were down.

Representative HOLIFIELD. From a remedial standpoint, this would be more valuable to those who had not received a lethal dose. To people, say, who received 100 or 200 roentgens, these measures would be of some value?

Dr. FRIEDELL. These measures may be valuable even at high doses, because it is possible—if 50 percent survive, say at 500 roentgens, it might be possible to push that up a little further, 60 or 70 percent. This is conjecture. We do not know. This is very important. When we get too high doses, over 1,500 roentgens, it seems that no measures are effective and we are unable to use any of these in any useful way.

Representative HOLIFIELD. Of course, from a practical standpoint, in an exposure of our people, it would be completely beyond the resources of the medical world to give this remedial treatment, would it not?

Dr. FRIEDELL. I think this could be true. But, if we are examining the whole problem, I think we would be overwhelmed by other things that would occur at the same time, and this would be essentially a small problem. There would be many, many more severe and difficult problems.

I have devoted my remarks primarily to the acute effects up to the present time, and we have talked about how we can assess these changes in the whole organism more or less immediately, and in fairly large doses.

It is well also to consider what would happen if the doses are lower, and if the animal survives. Is the animal completely unscathed if radiation has been delivered in smaller doses when comparatively few, or perhaps none have been killed?

Here I think we get into the problems that are very difficult to answer, and very difficult to prove effectively at the present time. This is an area where a great deal of study and research is required.

I would like to divide these, roughly, into three areas:

1. What is the effect on the vitality of the organism?
2. What is the effect on the production of malignant tumors?
3. What is the possible effect on future generations, the genetic effect?

The last I will speak very briefly upon, because many better speakers than I am will discuss it further. But I would like to say something about these points.

First of all, there is evidence indicated in animals with high doses—and by "high doses" I mean accumulation of many hundreds and even thousands of roentgens—that you can produce leukemia in susceptible strains.

I would like to point out that to produce leukemia a susceptible strain of mice must be used—that is, these mice must be such that they are genetically able to produce leukemia spontaneously. If the mice are not a susceptible strain—that is are not leukemia bearing—then the production of leukemia in such a strain is extremely difficult if not impossible. Thus one element that is essential is that the animal must have had inherent tendency to produce leukemia in the first place.

Secondly, tumors have been amply produced in animals with large doses of radiation, and tumors of all kinds. Whether it is strontium

90, phosphorus 32, or total body radiation, or radium, wherever you produce large doses and selective deposition in sensitive areas, you can produce tumors of all sorts. This is unquestioned.

Senator HICKENLOOPER. Benign, or other kinds of tumors?

Dr. FRIEDELL. Let us for the moment consider only the malignant tumors, tumors that will destroy the animal and fit all the criteria that people insist upon being characteristic of malignant, that is, they will spread to other tissues, and generally have the appearance of cancer. I think here is where we get into a problem.

If it is clear that there is evidence that tumors can be produced, and leukemia can be produced in various kinds of organisms under various conditions, it would be well to see if we could quantitate this. In other words, are there twice as many tumors produced when the dose is twice as high?

In general, this appears to be not well controlled, but there appear to be more tumors produced when the doses are higher. Under these circumstances, you can set yourselves up a little model or framework in which you show that the dose is related to the production of tumors, and the number of tumors.

Senator ANDERSON. Can I ask you there what you mean by "when the dose is high"? Can you give us the level again?

Dr. FRIEDELL. Yes. Generally, when we think of high doses, we think of doses in the lethal range, and perhaps I have been a little bit loose in this regard.

If you take animals that have been exposed to a lethal dose, 50 percent dose, that is, a dose in which 50 percent of the animals will succumb, and keep the survivors, the amount of radiation will be very high.

Senator ANDERSON. What I am trying to get to is this: We were talking previously about 5,000 to 10,000 roentgens.

Dr. FRIEDELL. Yes, sir.

Senator ANDERSON. Whereas, from fallout we are talking in thousandths, tiny fractions.

Dr. FRIEDELL. Yes, sir.

Senator ANDERSON. Now the things you are discussing, are they connected with fallout from nuclear weapons in any way, or an accumulation?

Dr. FRIEDELL. It is what we may be discussing, sir, and I would like to amplify this a little bit to show how this concept is approached. I will talk about those very low levels in just a moment.

Senator ANDERSON. All right.

Dr. FRIEDELL. In effect, what I am saying is large doses produce tumors and leukemia, and by "large doses," I am talking about thousands of roentgens, many hundreds of roentgens.

If you set yourself up a model in which you show that these doses will produce tumors and leukemia, and then extrapolate down to low levels, especially on the basis of how the data looked at high levels, you can begin to conjecture that perhaps these lower levels could in a very small percentage of patients or individuals produce these kinds of tumors.

Now, I think what we need to look at, and what this group is going to look at in the next couple of days, is how good are these extrapolations—Is this conjecture? Is this soundly conceived?

I wish I could offer an authoritative statement right now to end all of this discussion, but unfortunately I cannot. However, I would like to say this: That I am concerned about the fact that there are no data at the very low levels. It is just nonexistent. Much below a hundred roentgens, or 25 roentgens in the case of mutations, we have no data.

Representative HOLIFIELD. You are speaking of man?

Dr. FRIEDELL. In animals as well. I am speaking of all complex biological systems.

Representative HOLIFIELD. Have not you been able through following mice, for instance, through several generations, to establish any data of this type?

Dr. FRIEDELL. Yes, but these have been in large doses. These have not been in hundredths, or tenths of roentgens, they have been in doses far larger.

One of the reasons we are using large doses is that you have to have some kind of statistical security in looking at the information. To discover an effect which would occur once in 10,000 times, you would require an inordinate number of biological specimens, and so on.

But I would like to point out that this difficulty exists, and for this reason we do not have really secure data.

Now the people who propose that the doses at very low levels can produce effects have pointed out the data at higher doses are such that permit them to make these extrapolations, and there are many ways of looking at this. You can do it mathematically, you can do it by examing the mechanism by which these effects are produced, and in this way kind of develop some hypotheses which will permit you to make some conclusions.

I feel that the data at the very low levels are based on this kind of hypothesizing, and therefore, correctly are not available at the present time, and perhaps will not be available for a long, long time because of the difficulty.

We should, therefore, be slow in accepting these if we need to use it for a vital decision.

I think at the present time these data are not good enough to make very extreme or vital decisions in this regard. I think all of us should look at this to see what is the truth of the matter and what scientific evidence we can find which will permit us to make these conclusions.

Senator ANDERSON. May I try to translate that to myself and see if I got it correctly?

Dr. FRIEDELL. Yes, sir.

Senator ANDERSON. Do you tell us the data are not now good enough for the Congress, for example, to reach a decision on whether continuation of tests at the present level is wise or unwise?

Dr. FRIEDELL. I would say that, sir. I do not believe the data at the present time are good enough to make conclusive decisions.

Senator ANDERSON. If it is not good enough for the Congress, it is not good enough for the Atomic Energy Commission, either, then, is it?

Dr. FRIEDELL. Let me revise that statement.

Senator ANDERSON. That is the trouble. If it is not good enough for the Congress to reach a decision, it does seem to be good enough for the Atomic Energy Commission to reach a decision. They can sit in their ivory tower and say, "This is all right," but to get back to

the Congress which is having to deal with human beings, the data are not good enough.

Dr. FRIEDELL. I would say the data are not such as to suggest any vital or important decisions which would alter the course being pursued at this time.

First of all, they are not good enough to be conclusive, and there are other reasons I will go into further, which would make me have reservations on what they mean in general.

One of these is, when talking about these doses we are talking about the levels which fit into the dose levels we are receiving right now. If you are interested in numbers, each one of us are receiving or having about 3,000 to 5,000 ionizing events per cubic centimeter per second. Now it is 10,000, now it is 15,000, something of that order. So there are a lot of ionizing events going on now. We are living in a sea of radiation rising from various things, and this will be discussed, I am sure, or has already been discussed.

Senator ANDERSON. I think that is a very useful statement, and I appreciate it. I am only trying to say, if it is difficult for the Congress to get any satisfactory or conclusive answer from the existing data, that it must be equally disturbing, I would think, to the Atomic Energy Commission if they want to take a fair look at it. That is my only point.

Dr. FRIEDELL. I would think—if I were going to conjecture again, on how they are looking at it. I think they are disturbed by this, and I think their examination of the data would suggest to them there is no reason to stop these tests because of the levels of radiation. The levels are apparently at levels which are far below levels which we have established as being the acceptable doses, and are quite within the range of radiation occurring at the present time all around.

Senator BRICKER. Mr. Chairman?

Representative HOLIFIELD. Senator Bricker.

Senator BRICKER. Is there any thinking along the line that, if there were no background ionizing radiation at all, the human body would be devoid of cancer?

Dr. FRIEDELL. I do not have any opinion about this, sir. But again I will conjecture that I think the cause for malignant disease lies in some biological derangement that is really not related——

Senator BRICKER. To radiation?

Dr. FRIEDELL. Alone.

Senator BRICKER. But ionization of the cells?

Dr. FRIEDELL. Right.

Representative HOLIFIELD. You used the word "alone"; it is not related alone to that point. You think there may be other causes? I was afraid that word was missed by the audience. I think it is important.

Dr. FRIEDELL. I think at the proper levels, high enough levels, these effects can be produced. At the very low levels where the levels begin to approach the natural levels we are facing, I think there is grave uncertainty. This, of course, is concerned with the whole concept of whether the effects will be occurring at low levels in the same rate that they are occurring at high levels, and whether there is such a thing as threshhold. In other words, is there some level below which nothing will happen?

Again, this is very difficult to establish. The evidence, as I see it, is inconclusive in this direction, and if I had to choose, if I had to make a decision now, if I were compelled to make a decision, I would hesitate to accept this concept that a threshhold does not exist.

Senator BRICKER. That is the reason I asked the question, frankly. It is your thinking, then, that there is a biological cause of these abnormal growths in the human body?

Dr. FRIEDELL. I do, sir.

Senator BRICKER. Above and beyond and separate from the radiation?

Dr. FRIEDELL. Yes; I do.

Representative HOLIFIELD. Will you state your observation in an affirmative way rather than a negative way? And then tell me if you apply that equally to somatic as well as reproductive cells.

Dr. FRIEDELL. I sort of left out the reproductive aspect of this.

Representative HOLIFIELD. That is just what I thought maybe you left out. That is why I wanted you to restate it.

Dr. FRIEDELL. I would say, from the point of view of production of tumors, and leukemias, I would hesitate to accept the concept that a threshold does not exist. From a point of view of genetics—now I am in a field where I am even less familiar—I think the data are not unassailable, but I think they are stronger than they are in the concept of cancers or leukemias.

Again I would like to point out the data on mutations and genetic effects do not exist below 25 roentgens.

The basis for making these decisions is careful study of the data, by protracting the radiation, by fractionating it, by observing the effect of dose, and this gives them a line which can be extrapolated down below. I have no objection to these extrapolations, and ever since Descartes introduced the coordinate system, this is a privilege of all. I do not really understand whether these things necessarily follow this rule. I would think I would want a much better and much more carefully controlled examination of the effect at very low levels.

Representative VAN ZANDT. Mr. Chairman?

Representative HOLIFIELD. Mr. Van Zandt.

Representative VAN ZANDT. Dr. Friedell, to be conclusive, would you go into a little more detail as to what must be required?

Dr. FRIEDELL. What must be required?

Representative VAN ZANDT. Yes.

Dr. FRIEDELL. As far as our studies go?

Representative VAN ZANDT. Yes.

Dr. FRIEDELL. I think probably the most important thing is to look at the basic aspects of what occurs in biological systems, so that we can understand the mechanism, so that we can see whether once we understand this mechanism it fits in with the data which we already have. And here I feel is where the greatest possibility for really learning something about it exists. I would like to see this emphasized over and above the efforts to perhaps use 10 million mice at very low levels. I would think that basic studies of biochemical effects, the possible way in which these things occur, would contribute more than doing such statistical studies——

Representative VAN ZANDT. Would you apply a time factor?

Dr. FRIEDELL. I would hesitate to apply a time factor, but since I am making all sorts of conjectures, I will add one here.

I will say that perhaps in 5 to 10 years we would have a much better understanding of this.

Representative HOLIFIELD. Of course, if your understanding at that time had to be revised downward as the chart this morning has been revised downward, we would be dealing then with an accumulation of substance which would be ineradicable, and we would have it; would we not?

Dr. FRIEDELL. Yes.

On the last page of my little statement, I tried to put these things together. I think two problems exist.

First of all, I think there is a problem of examining the data scientifically to know where the truth lies.

Assuming the correct consequences of this, assuming no threshold, and all radiation is injurious and produces some effect, I think we have to fairly assess this kind of hazard compared with the hazard which now exists. I do not feel we have yet really looked at this in an unbiased and nonemotional manner. I think it can be done, especially if we look at it over a long period of time so we do not rush into any important decisions at this time.

Senator BRICKER. You have discussed the control of abnormal growths, the cause of them, the somatic effects in a limited way. What have you to say about the length of life?

Dr. FRIEDELL. Here again I do not have any good, well-founded opinion. The data that are available indicate that for large doses in animals, there is a decreasing survival due to all the causes that would occur ordinarily in these animals. In other words, they die of various things, only these various causes of death appear a little earlier in heavily irradiated animals.

Again the same problem exists. Can you extrapolate down below?

This figure we heard earlier that somebody will have suffered a loss of 20 days in survival. It seems to me there can be no data at this level, because this would require an inordinate amount of animals at very low levels to establish this, and I just do not have that kind of sureness about studies in which you observe one event in hundreds of thousands of others.

From the point of view of the span of life, I feel for projections to low levels this falls in exactly the same kind of category. We cannot determine what is happening at very low levels.

I think I can understand the reasons and conjectures and hypotheses of people who propose that this occurs, but they make me uneasy, and I am loath and not ready to fully accept them. I think they are not incontrovertible.

From the point of data on humans, there is some published evidence to show a radiologist may, by the nature of his activities, have received more radiation than others. I am a radiologist myself. I turned some data recently published over to the statistician, and he wrote me a letter saying that these data were suggestive, but by no means conclusive. And the way in which you sample the various groups makes a tremendous amount of difference, and even though averages of the compared group, for example, might be the same, the distribu-

tion could make a tremendous difference. I know this has been touched upon by others who feel the same way.

Representative HOLIFIELD. We found that averages are a little bit unreliable to rely on in some instances.

Dr. FRIEDELL. Yes.

Representative HOLIFIELD. Thank you very much. Are you planning to stay the rest of the day? We might have you on in the discussion late this afternoon.

Dr. FRIEDELL. Yes, sir.

Representative HOLIFIELD. Thank you, sir. Your prepared statement will be placed in the record at this point.

(The prepared statement referred to follows:)

MATERIAL PRESENTED BEFORE THE JOINT COMMITTEE ON ATOMIC ENERGY BY H. L. FRIEDELL, M. D.

The biological effects that are observed when tissues are irradiated must begin as a result of the physical interaction of ionizing radiation and the atoms that comprise the biological specimen.

This interaction appears primarily as ionization—that is, ejection of an electron from the orbit by excitation, in which the energy level of the electron without ejection probably also plays a part.

The excited and ionized atoms and molecules then appear to interact in various ways, eventually producing profound chemical and biochemical change. The immediate physical and chemical changes are probably over in fractions of a microsecond, or at most a few microseconds. The biological effects may not appear for hours, days, or months.

One interesting aspect of this energy absorption is that only a small absorption of energy produces such widespread biological effects. One thousand roentgens, a lethal dose, involves only a very small fraction of a calory per gram (2×10^{3} calories per gram). Another way to look at this is that the energy which is absorbed appears to affect directly only about 10^{7} molecules in a cell which generally contains 10^{14} molecules.

In outline form, we need to think of the chain of events as (1) physical interaction, (2) chemical and biochemical changes, (3) cellular changes, (4) going on to tissue and organ system alteration, and, finally (5) injury to the whole organism.

The chemical and biochemical effects which occur are at the present time somewhat obscure and receiving much study. One of these effects that has been of interest and which appears to be tied up with some of the observable biological changes are the indirect effects resulting from the disruption of the water molecule abundantly present in living tissue. In the presence of oxygen, this results in producing highly active water radicals which in turn attack vital molecules in the cell since they are very active oxidants.

It has been found that, by depriving the cell of oxygen during the radiation period, these effects can be markedly minimized. By introducing chemicals which are in themselves oxygen acceptors, the oxidation effect on sensitive tissue systems may be spared and the radiation injury is markedly minimized.

At the present time, the best working concept is that the indirect effects are very important at the levels of radiation with which we are concerned (500 to 1,000 r.), that efforts to correct or prevent the chemical and biochemical disturbances as a result of disruption of the water molecules protects biological systems in an effective manner. It should be pointed out that this must be done during the radiation and is completely ineffective after the radiation has been delivered.

The cellular effects have been quite thoroughly studied. On the whole, the nucleus is known to be more sensitive than the cytoplasm. Cells appear to be affected primarily with respect to their function of division and recent studies have, therefore, been directed at this aspect. From the biochemical point of view, the nucleic acid metabolism, and particularly DNA in the nucleus, has received considerable attention.

From a general point of view, it is best to look at the cellular changes and try to understand the difference between cells and their place in the economy

of the whole organism. At one end we have extremely sensitive cells. These may be listed as follows:

(*a*) Extremely sensitive: Lymphocytes, erythroblasts, germinal epithelium of testis, myeloblasts, germinal cells of ovary.

(*b*) Highly sensitive to moderately sensitive: Epithelium of intestinal crypts, basal layers of the skin.

(*c*) Insensitive: Connective tissue, bone, liver, pancreas, kidney, nerve, brain, muscle.

An estimate of the variation in sensitivity permits us to understand better the effects on tissue and on the whole organism. The effect on the whole organism is obviously determined by how dependent the organism is upon extremely radiosensitive tissues. Since the hematopoietic system is one of the extremely important tissues upon which the organism vitally depends, it can be explained that irradiated animals can be readily injured by comparatively modest doses. The animals suffer infections and will die a hematopoietic death if some measure for correction is not instituted. The epithelium of the gastrointestinal tract is less sensitive but nevertheless readily affected by large doses of radiation. At the lower dose levels there is rapid recovery. At the higher dose levels recovery is markedly impaired and the animal may succumb to what is known as a gastrointestinal death, sometimes even before the hematopoietic changes can manifest themselves.

Many tissues are quite unaffected by radiation at levels which would cause death of the whole organism. Therefore, under certain circumstances, particularly when certain radio elements are used, considerable radiation may be delivered without seriously affecting the organism as a whole since the radiation is confined to a comparatively insensitive structure. Also, radiation delivered to sensitive tissues which may not be vital to the organism proper will have comparatively little effect on the individual. As an example, radiation delivered to the thyroid, which in older individuals is comparatively insensitive to radiation, will not produce any appreciable effect on the whole organism. Also, radiation delivered in modest doses to the gonads may produce sterility but will otherwise appear to have no demonstrable effect on the individual proper.

It would be well to point out that the manner in which radiation is delivered is highly important in considering the possible biological effects (excepting genetic changes which will be discussed briefly later). Protraction and fractionation of the radiation markedly reduces the total somatic biological effect. Radiation delivered to specific parts of the body markedly alters the response so that shielding of part of the body increases the dose necessary for lethal effects.

Generally, radiation delivered over a long period of time gives some of the tissues an opportunity to recover (a process which is poorly understood) and, therefore, increases survival.

Specifically, it is well to point out that species sensitivity varies among mammals. Following is a list which gives some concept of the range that may exist:

LD_{50} dose:	*Roentgens*	LD_{50} dose:	*Roentgens*
Guinea pigs	200	Rats	700
Pigs	300	Hamsters	750
Dogs	350	Rabbits	800
Mice	450	Bacteria	100,000
Monkeys	500	Viruses	1,000,000

Man is estimated to fall somewhere halfway through this range of mammals and the LD_{50} dose (that is, the dose necessary to kill 50 percent of the individuals) is presumed to be about 500 roentgens.

As a result of whole-body radiation, certain specific tissues effects are produced. These in turn determine the clinical syndrome. Briefly, the effects which first appear are nausea and vomiting, which can be explained on the injury to the gastrointestinal tract. Prostration, diarrhea, and anorexia may promptly occur with larger doses—again the result of interference with gastroitestinal function and dehydration. The blood forming tissues are simultaneously affected, but evidence of their severe depression is slightly delayed. There is marked depletion of the white cells—later the red cells. The elements involved in clotting are seriously affected and hemorrhages as a result of this derangement soon appear. The individual is susceptible to infection for two reasons—one, depletion of the white cells, and secondly, by impairment of the ability to form antibodies. As a result of this susceptibility to infection, the

oropharynx, respiratory and gastrointestinal tract are prone to ulceration and infection. The central nervous system is essentially not affected.

The neuromuscular system and the specific function of the liver and kidney appear not affected at lethal doses, fitting in with our general concept of radiation sensitivity of tissues. Epilation occurs as the dose approaches the LD_{50} range, since the basal cells of the skin and their derivatives are quite sensitive.

Of concern also are effects which do not appear immediately as the result of radiation but are either postponed until late in the life cycle of the organism or may be observed only by special methods of testing. One of these is the question of general impairment of viability of the organism which may be susceptible of determination by observation on longevity.

In animals at fairly large doses there is good evidence that animals do not survive as long as nonirradiated controls. Whether this may be extrapolated to low dose levels is uncertain and is by no means conclusively established. There are no good data at levels of less than 100 roentgens and those that are available do not indicate any change in longevity. Recently, there has been presented evidence that radiologists who, having received more radiation than others by the nature of their activities, have suffered a reduction in their life span. Although the data are suggestive, statisticians have seriously questioned the significance of these data because of the method of sampling and of the uncertain relationship of the age groups.

Another late consequence of radiation in which the animal survives is the production of malignant new growths (tumors of various kinds) and leukemia. In animals, large doses unquestionably produce an increase in the incidence of cancers and leukemias. It should be pointed out that it is necessary to use a susceptible strain and that in certain insensitive strains it is not possible to produce these changes. The question as to whether this occurs in man, I think, has been amply demonstrated.

I believe there is evidence to show that when humans are heavily irradiated, tumors and lukemia will appear. The question is whether this occurrence may be satisfactorily quantitated and attributed to low levels of radiation. We have no data in this respect. Theoretically, considerations suggest that this may occur, but at present are entirely in the realm of hypothesis and must be considered inconclusive.

A third important late effect is concerned with the injury to the genetic tissue of the organism, and here I believe we should now make a distinction between sterility and genetic alteration.

The cells of the gonads which develop into sperm and ova and concerned with reproduction are extremely sensitive—comparable to that of hematopoietic tissue, and are injured with modest doses of radiation. From the point of view of sterility, it requires about 300 to 400 *r* to induce sterility in the female and perhaps 500 *r* to induce sterility in the male—that is, there is essentially complete loss of viability of the reproductive cells so that no progeny is possible.

This must also be distinguished from injury to the cells in the reproductive organs having to do with sexual characteristics—that is, male and female characteristics and other hormonal influences. These cells are not readily injured by radiation and are comparatively insensitive. Although it is easy to produce sterility, it is very difficult to eliminate the normal sexual characteristics—that is, male and female characteristics and other related functions.

The important change which has significance for all of society concerns itself with the alteration of the genes proper. Without going into the concepts of physical characteristics of the gene and its position in the reproductive apparatus, it is sufficient to say that these alterations are known as mutations which are essentially uninvolved in the reproductive capacity of the individual but produce its effects in subsequent generations.

Briefly, these mutations as a result of radiation appear to be similar to mutations produced by other causes. (Radiation is not the only cause for mutation.) The number of mutants appears to be directly related to the amount of radiation; that is, doubling the dose doubles the number of mutants. It is presumed that the radiation would have exactly the same importance and effect no matter how low the radiation level. It should be pointed out that we have no data below 25 roentgens and that extrapolations to very low levels are made on theoretical grounds.

It has also been generally accepted that the radiation effects on the extent of mutations are cumulative. That is, whether the dose is given at one time or distributed over long periods of time, the effects are exactly the same. Although

these data appear sound, they may still be considered incomplete and there are minor discrepancies which have appeared and which may require some elaboration. There is also reason to discuss the place of the production of mutations compared with the general mutations that are being retained in the genetic pool.

The radiation dose necessary to double the mutation rate appears to be about 50 roentgens. It should be clearly understood that this is an estimate, and competent geneticists have submitted proposals from 5 to 150 roentgens.

It is known that there are many diseases of heredity (that is, genetic origin) which are almost certainly the result of mutants and may therefore be examined in the same light as mutants due to radiation. Since these may be retained in the pool because of the amelioration of the rigors of selection, it would be possible to assess all of these mutants in terms of roentgens. Therefore, a better estimate of the total hazard as a result of low doses of radiation would be possible.

It appears that most mutations appear to be of the recessive variety which would therefore, in effect, not permit their immediate recognition or elimination until after many, many generations. This means that the mutant will become widely disseminated in the genetic pool. It also means that the radiation received by a small segment of society may be of little consequence since the radiation to the total population would be roughly the ratio of the total population to this small segment. The genetic effects are best surveyed from the point of view of its effect on the whole population and, generally speaking, the genetic effects become significant when delivered to either the whole population or large segments of it.

I am inclined to make these observations from the point of view of long-term effects of radiation—that is, the production of tumors, leukemia, and the decrease in longevity.

All data presented at the present time are either presumptive or speculative for very low doses. They rest in hypotheses derived from the theoretical aspect of dose effects at high levels. I believe there is sufficient uncertainty so that it would be unwise, and in fact nonscientific, to make conclusive decisions on the basis of these extrapolations.

With respect to the genetic effects, which have been extensively studied by biologists, there are sufficient uncertainties even in these data so that it is not possible to accept them as entirely unassailable. These include the fact that data at low levels do not exist, that data are confined at present to Drosophila and to a few small mammals such as mice, that the mutation rate due to ultraviolet radiation appears to be nonlinear, and there is reason to believe that some of the energy transfer with ionizing radiation is in part of the same character as that with ultraviolet radiation. Man has existed since time immemorial in a sea of radiation where fairly large differences because of altitude and special geographic places also are present. It is difficult to reconcile some of the conjectures to be made at very low levels with the natural radiation doses to which man has already been subjected.

To my mind, the problems of biologic effects at low doses are in essence these:

1. The data on the biological effects at low levels of radiation are by no means conclusive. At best they must be considered highly presumptive This suggests that extensive, carefully considered research is necessary.

2. Even if one assumes that the low-level effects of radiation are established, the problem of establishing the hazard and the risk rate at these levels has not yet been fully and properly evaluated. With specific regard to the fallout problem, it is my opinion that at the low levels which now appear to exist, no immediate decision on any vital problems is now necessary.

With respect to the general overall consideration regarding all-out nuclear warfare, a different order of magnitude is introduced and I must join with others in pointing out that this is fraught with the direst consequences, and that every effort must be expended to the elimination of nuclear warfare.

With specific respect to the fallout problem, it is my opinion that with the low levels which now exist, no precipitate alteration in our course is required. There are a number of organizations on radiation protection that are continually looking at this problem with representatives of all disciplines, and they are gradually modifying the acceptable levels wherever it is found desirable.

Representative Holifield. Before we hear our next witness, I would like to insert in the record a report from the Armed Forces Institute of Pathology.

(The report referred to follows:)

ARMED FORCES INSTITUTE OF PATHOLOGY,
WALTER REED ARMY MEDICAL CENTER,
Washington, D. C., May 16, 1957.

Subject: Statements for congressional hearings.
To: Chief of Research and Development, Department of the Army, Washington, D. C.
(Attn. Chief, Atomic Division.)

The following report is submitted in accordance with a verbal request to the Director of the Armed Forces Institute of Pathology from Lieutenant Colonel Ransom of the Research and Development Office of the Department of the Army, May 14, 1957. The time limit of 24 hours for the preparation of such an extensive report, and the absence on TDY of the Chief and Assistant Chief of the Section on Radiobiology, Armed Forces Institute of Pathology at the Nevada test site on Operation Plumbob 4.1 necessarily resulted in some limitation on presentation of material requested which under more favorable circumstances could possibly be more fully covered. The discussions and answers as presented represent a combined effort of the professional staff of the Armed Forces Institute of Pathology with some assistance obtained from Naval Medical Research Institute and Walter Reed Army Institute of Research.

W. M. SILLIPHANT,
Captain, MC, USN, The Director.

CONCERNING TOPIC IX

A detailed discussion of the occurrence of strontium 90 and cesium 137 in the atmosphere and its uptake and behavior in man is contained in the remarks prepared by Dr. Willard F. Libby, Commissioner, United States Atomic Energy Commission, for delivery before the spring meeting of the American Physical Society, Washington, D. C., April 26, 1957. A copy is attached (see p. 1519). These findings have also been discussed and confirmed by Drs. J. L. Kulp, W. R. Eckelmann, A. R. Schulert (Strontium 90 in Man. Science, 125, p. 219, February 8, 1957). However, Dr. Lapp (Science, vol. 125, p. 933, May 10, 1957) criticizes some of these conclusions, and points out some pertinent factors for consideration. His critique is attached (see pp. 694, 704).

CONCERNING TOPIC X

SOMATIC EFFECTS—PATHOLOGY

A. Distinction must be made between the somatic and genetic effects of radiation

The genetic cells carry on from generation to generation the damage which has been received. The somatic cells receive the injury but this is not transmitted from one generation to another. The effects of high level radiation may be manifested not only immediately but also after a delayed period. There are also effects from a low level of radiation and some organs are more readily injured than others.

B. Early effects of exposure of animals and man to external radiation

1. *Gama and X-radiation.*—Syndrome of radiation sickness. Individuals receiving doses of total body radiation can probably be best divided from a standpoint of prognosis according to the clinical signs and symptoms they present. This is particularly true because of individual variation in the response of different people to the same dose of irradiation. Roughly, casualties may be grouped into those in which survival is improbable, possible, and probable.. There is, however, no very sharp line of demarcation among the groups. The signs and symptoms have been described for the Japanese casualties at Hiroshima and Nagasaki in a report by Liebow, Warren, and DeCoursey in the American Journal of Pathology and in a report entitled "Some Effects of Iionizing Radiation on Human Beings" involving particularly the Marshallese casualties. In doses of more than 3,000 roentgens one may encounter a hyperacute reaction within an hour whereas in the range of about 3,000 to 2,000 roentgens nauseau, vomiting, and some diarrhea and fatigue may be the initial reaction in 2 to 4 hours after exposure. In individuals receiving doses between the range of 2,000 down to 800 roentgens there may be a period of relative well-being following the initial reaction for a few days and then a gradual return of

anorexia, malaise, severe diarrhea, thirst, fever, delirium, and leucopenia. In individuals between 800 and 300 roentgens this reaction may come in about 2 to 3 weeks with acute bone marrow failure, ulceration of the gastrointestinal tract, epilation, and bacterial infection. A subacute reaction consisting of subacute marrow failure, subacute infection in the lungs, brain, and bowel and general malnutrition may manifest itself in about 6 weeks after exposure in patients receiving 350 to 250 roentgens. In those receiving less than 250 roentgens and in some survivors from doses in the lethal range, there may be a chronic reaction of varying degrees extending for a period of months or longer of malnutrition, chronic anemia, premature aging, leukemia, and possibly neoplasia. The above acute syndrome varies with the geometry of the source of radiation in relation to the exposed person.

(*a*) Marshallese: See reference.

(*b*) The Los Alamos incidents referred to under X, B, 1, b are covered in a single entire issue of the Annals of Internal Medicine February 2, 1952.

2. *Beta radiation—Beta burns.*—As long as only very penetrating radiations are involved in exposure of the entire body, skin injury would rarely be a problem, because a dose sufficient to permanently affect it would kill the patient before dermatologic lesions were of any concern. Epilation is an exception to this statement since it was present, though only temporarily, in some of the Japanese atom-bomb victims. During fallout from bomb clouds, however, radioactive particles may settle on the exposed skin of anyone outdoors, and the hazards of beta particle radiation burns are added to the effect produced by penetrating gamma rays. Beta particle burns resulting from fallout first came into public prominence with the announcement that some of the inhabitants of the Marshall Islands were exposed to such a hazard during the 1954 weapons-testing program. However, the problem of fallout was not a new thing to those charged with the responsibility of conducting tests of nuclear weapons. At the time of the first nuclear detonation at Alamagordo, N. Mex., a number of cattle about 10 miles from the blast received fallout on their backs. The fine particles were retained by the hair, and in a few weeks epilation and blisterlike lesions occurred. The lesions healed much like ordinary thermal burns, and the hair grew again, but the original red color was replaced by grey or white. Late effects of this exposure have recently been reported in studies conducted at the AFIP.

(*a*) Marshallese: In the Marshallese group individuals were exposed to gamma and beta radiation. The injuries due to beta burns were local and confined to the areas of contact. The reaction manifested itself by initial tingling and itching at the time of exposure, followed by erythema and edema in a few hours, lasting for 2 to 3 days. There was then a latent asymptomatic 3- to 5-day period with a return of secondary erythema with vesicle formation. Drying and desquamation takes place in about 3 weeks and the individual then may enter a chronic phase with some atrophy of the involved parts taking place. Where both types of radiation occur concomitantly, the gamma radiation generally overrides the beta in clinical significance.

The effects of ionizing radiation amongst the Marshallese has been extensively covered in the report Some Effects of Ionizing Radiation on Human Beings from the Naval Medical Research Institute, Bethesda, Md.; United States Naval Radiological Defense Laboratory, California; and Medical Department, Brookhaven National Laboratory, Upton, N. Y.; United States Atomic Energy Commission, July 1955. Values for gamma and beta radiation could only be approximated but there was a high enough dose on the skin to produce lesions. The estimated "point source" doses were:

Rongelap, group I, 260 r.
Uterik, group IV, 20 r.

Some of the patients showed acute symptoms of diarrhea and vomiting and itching and burning of the skin in group I (Rongelap) but none in group IV (Uterik) showed these symptoms. Biopsies were taken of the skin at various stages. These showed changes typical of radiation reaction. Ultimately there was complete restoration of the skin.

(*b*) Other examples: Skin lesions, acute, chronic and neoplastic were one of the earliest hazards to be recognized in human beings exposed to low energy radiation. Human casualties from ionizing radiation have been of increasing concern since the turn of the century. These include in addition to skin lesions, a higher incidence of leukemia among radiologists than among the general population. The occurrence of cataracts among early workers with cyclotrons, the

high incidence of cancer of the lungs as an occupational hazard among certain miners in Czechoslovakia, and the bone cancers that occurred in watch dial painters in this country.

(c) *The early effects of internal radiation are dependent upon the amount, type, and area where material is deposited*

If the material is insoluble and taken into the gastrointestinal tract, it might produce only local irritation of the intestinal tract but not be absorbed within the body economy. Another example would be in giving I–131, the early manifestations of which would be some soreness of the thyroid and hematopoietic changes (approximately 2 to 3 weeks). However, this would require a large therapeutic dose.

(d) *Criteria include*

Half life (the physical and biological half lives), body utilization, solubility and excretion.

(e) *The degree to which late effects, readily produced in animals by single "massive" doses of total body ionizing radiation, may turn up in survivors in Japan is still under investigation*

Such effects include the occurrence of tumors in various organs after long latent periods following a single exposure to total body radiations in the lethal dose range; genetic mutations that affect subsequent generations; and aging. Such injuries are obviously far more difficult to follow in man than in controlled laboratory animal populations. It is only very recently that quantitative data on genetic mutations have been extended from fruitflies to a mammal, namely, the laboratory mouse, and this may still be a long way from the problem in man. An increased incidence of myelogenous leukemia and radiation cataracts has been found in the followup studies of the Japanese to date.

In the course of radiotherapy, it seems that serious late effects can result from a single exposure or a series of exposures to X or isotopic radiations. Thyroid cancer has resulted in children being given X-radiation for thymic disease. Leukemia has also been reported in individuals receiving X-radiation for spondylitis or those receiving repeated I–131 for cancer. The increased incidence in leukemia in the Japanese exposed to nuclear explosions at Hiroshima and Nagasaki is the only example of this disease occurring in man after a single acute exposure of the entire body to ionizing radiation.

(f) *General*

Exposure of the entire body, or a major portion thereof, to significant amounts of penetrating ionizing radiation interferes with the proliferation of normally self-replenishing tissues essential to life, namely the bone marrow, and under certain circumstances, the small bowel epitheliu. Within the lethal dose range, most of the stem cells responsible for the continued replacement of these tissues are still capable of recovery, with survival being dependent upon the time and extent of regeneration. The acute radiation syndrome, therefore, is a clinical entity resulting from an action of ionizing radiation from which recovery is potentially possible. It is a diagnosis that includes the signs and symptoms that evolve following exposure of the whole body or a major portion thereof to penetrating ionizing radiation.

It has been estimated that the human bone marrow pours into the blood stream each day 1 trillion red blood cells, 10 billion granulocytes and 500 billion platelets. The epithelial lining of the small bowel of a rat is replaced every day and a half. In the human, the rate of replacement is not accurately known, but it is also quite rapid. The rate of cell division in these tissues, throughout life, is as high as that encountered in a great many malignant tumors. Interference with the continuous proliferation or replacement of these tissues results in a secondary aplastic anemia and damage to the integrity of the alimentary tract.

The sequelae of panhematocytopenia from any cause have been known for a number of years. They include (1) thrombocytopenic purpura, (2) anemia, and (3) agranolocytic infections.

Anemia is due to a variety of factors including (1) inadequate hematopoiesis, (2) widespread purpuric hemorrhage, and (3) increased destruction of red blood cells. Hemorrhage is most prone to occur at sites of injury due to radiation damage, accidental trauma, and physiologic activity. Huge numbers of extravasated erythrocytes return to the bloow stream via the lymphatic system and thoracic ducts. Many are phagocytized by macrophages. Increased destruc-

tion of red blood cells occurs, and leads to increased deposits of hemosiderin in the spleen.

Vincent's Angina is a common complication of agranulocytosis from any cause. Mechanical trauma and poor oral hygience invite septic ulcerations, particularly in the presence of agranulocytosis. The tonsils, as is well known, may serve as portals of entry for bacteria with the subsequent development of a bacteremia or septicemia.

Focal hemorrhages from radiation-induced thrombocytopenic purpura may be followed by septic ulcerations of the large bowel and the onset of diarrhea several weeks after exposure, even though the dose of radiation to the abdomen has not been sufficient to permanently interfere with recovery of the more radiosensitive small bowel. Such things as focal hemorrhages, delayed vascular reactions to irradiation, and to injured tissue, damage to the solitary lymphoid follicles and smoldering superficial infections contribute to the development of such ulcers.

Recovery of the small bowel epithelium generally occurs following exposure to total body ionizing radiation up to 100 percent lethal dose. Failure of recovery, however, may be an important factor in early deaths resulting from exposure to supralethal doses, or where the small intenstine is the principal site of injury.

1. In the various mechanisms of response of man to radiation the injury is caused by the energy imparted by the various ionizing radiations. This energy is dissipated in matter through excitation or ionization, depending upon the energy level of the radiation. The total ionizing action is related to the number of ion pairs formed per unit limit. This may be expressed as the density of ionization. Alpha particles have a high ionization density but a short range; beta particles a less dense ionization pattern but a range of a few millimeters in tissue and a few centimeters in air. Gamma radiation has a long range with the lightest ionization density. Neutrons have a somewhat shorter range than gamma rays. This is significant in that gamma and neutrons can penetrate with ease into the body from external sources. In contradistinction, alpha and beta particles are limited in such penetration from practically 0 for the alphas to a few millimeters through the skin for the betas. However, from an internal source, alpha emitters take on particular importance because of their unrestricted local activity over very long periods of time.

Certain effects of ionizing radiation on living cells in both plant and animal tissues have been clearly established for many years. These include (1) acute cell destruction, associated with nuclear vacuolization, rupture, and fragmentation; (2) a variety of chromosomal alterations and; (3) delay in division. Less well understood actions include (1) differentiations, aging and death of so-called vegetative intermitotic or stem cells; (2) effects which interfere with the action of humoral factors involved in the regeneration of certain tissues, including derivatives of the reticuloendothelial system; and (3) effects involving the cellular and noncellular immune responses of the organism.

2. Significance of different types of ionizing radiation in process: There are several important differences between lesions to be expected from penetrating radiation and from beta radiation from fallout particles. Once the beta particles have reached the surface of the earth, they contribute to the general activity of the area, but do not endanger the skin surfaces to any extent, because they penetrate only a few millimeters of tissue and almost any covering affords some protection. Overexposure to gamma rays may be followed by the acute radiation syndrome, and death or recovery in a matter of weeks, while exposure to high levels of beta radiation may result in third-degree burns requiring long hospitalization and extensive skin grafting.

In early casualties due to fallout in the general vicinity of the nuclear weapon used, one is concerned chiefly with the "recoverable component" of radiation injury. With such fallout pattern, depending on meteorological conditions downwind from the site of detonation, the terrain, weapon, point of detonation, etc., time, intensity and quality factors of irradiation become as important for prognosis, as they are in formulating a radiation prescription for the treatment of malignant disease. From a research standpoint also, the recoverable component of irradiation injury appears to be the key to survival following total body irradiation.

3. Ionization is thought to result in the breakdown products of water in the presence of oxygen into OH, H, O_2H, and H_2O_2; with the exception of hydrogen, these are powerful oxidizing agents. As to the locus of the radiation effects, in cells, two theories are advanced. One, the target theory localizes the action with some vital component of the cells. The other, the indirect theory, relates more

to the general action of the breakdown products of water. Both types of action probably account for radiation injury. One of the most important cellular effects is enzyme alteration. This generally occurs by oxidization of the SH groups or by protein denaturation. There is also a reduction of nucleic acid synthesis and arrest of mitosis. The use of the terms direct and indirect effects of irradiation should distinguish whether one is speaking of a single cell or the whole organism. Thus, ionizing radiation effects on the small bowel epithelium are direct in the sense that they are not appreciably inflamed by shielding various portions of the body other than the area of small intestine irradiated. Such effects within a single proliferating mucosal crypt cell may be both direct and indirect, although the latter, presumably mediated by the production of certain highly reactive radicals, appear to be the most important.

Various tissues of the body respond quite differently, in terms of ultimate effect, to the same cumulative dose of irradiation—total body and otherwise—fractionated in different ways. (See also data by Nachmansohn and Cotzias and Serlin under X, Bl.)

4. As a general rule, the sensitivity of a call to radiation varies as the mitotic activity and inversely as the degree of differentiation. Ranging from the most sensitive to the least sensitive, are the lymphocytes, erythroblasts germinal epithelium of tastes, myloblasts, intestinal crypt epithelium, ovarian germinal cells, basal layer of skin, connective tissue, liver, pancreas, kidney, bone, brain, nerve, and muscle. It is important to distinguish between radiosensitivity and radiocurability as well as the biological effect under consideration.

5. Effects of the whole organism.

(*a*) There is a wide difference in susceptibility of various animals to total body irradiation. The approximate LD 50/30 doses of total body radiation are as follows:

	Roentgens		*Roentgens*
Guinea pig	250	Rat	590
Dog	300–430	Mouse	500–650
Swine	420	Burro	580–780
Man	450 (estimated)	Rabbit	790–875
Monkey	500 [1]	Chicken	1,000
Sheep	520	Turtle	15,000

[1] For servival period of 67 monkeys at various gamma radiation doses see Effects of Barium^{140}–Lanthanum^{140} etc., under B.1. For recent review of the Effects of Radiation in Mammals, E. P. Cronkite and V. P. Bond, American Review of Physiology, vol. 18, 1956.

The difference in the lethal dose of total body irradiation upon various mammalian species: guinea pig, 200 roentgens, rabbits, 800 roentgens, has been directly correlated with degree of the recovery of delay in bone marrow produced in the particular species involved by such dose.

(*b*) Micro-organisms vary tremendously in their susceptibility to radiation. To destroy all bacteria in milk, for example, requires at least 750,000 roentgens. Tobacco mosaic virus requires 1,800,000 roentgens.

(1) Position of man: There are no exact data. The LD50 figure of 350 roentgens proposed from the Marshallese contrasts with a commonly quoted value of 400 roentgens or 450 roentgens. (Handbook of Atomic Weapons for Medical Officers prepared by the Armed Forces Medical Policy Council for the Army, Navy, and Air Force, June 1951), and a recent evaluation of the Japanese World War II casualty data something in figures well bove 400 to 450 roentgens for the immediate radiation from the bomb. (See Marshallese report).

6. The clinical syndrome in man of radiation injury in the sublethal and lethal range presents a fairly uniform hematopoietic pattern. In the sublethal group, there is an early and profound drop in lymphocytes with the neutrophil count showing an initial rise in 12 to 48 hours and then falling to pre-exposure level with a maximum drop from 5 to 6 weeks. Platelets start to decrease in a few weeks with a maximum low in about one month. During the first few weeks the hematocrit falls off only slightly if there is no bleeding. In the lethal ranges the same course of events occur but are markedly acceleraed and of greater intensity. The platelets drop off by the 4th day and completely disappear by the 10th. This general hematopoietic depression ties in with the subsequent bleeding and infection susceptibility. In the delayed effects the shortening of life span may result from such general factors as lowered immunity, damage to connective tissue, and premature aging. The question of specific tissue damage is indicated by the increased tendency to leukemia and skin cancer in certain exposed individuals. However, the carcinogenic factor is not too well established in humans.

For syndrome of nervous symptoms, see joint report of Hiroshima and Nagasaki casualties, etc., by Shiraki et al., under X, B,1. Also in National Academy Sciences report, 452, pages v-5–v-62.

G. Relationships of damage mechanisms to dosages

1. Production of leukemia and neoplasms (under mechanisms and response of man to radiation and radioactivity) exposure to ionizing radiation has been generally accepted as a leukemogenic factor in man (Kaplan, H. S., Cancer Research, 14, 535, 1954).

The high incidence of leukemia in radiologists, 8 to 10 times the incidence in nonradiologists has been widely accepted as evidence of this factor (Ulrich, H., New England Journal of Medicine, 234: 45, 1946). Further evidence has been the cases of leukemia and malignant epithelial lesions (Hepatomas) many years after the diagnostic use of Thorium dioxide (Thorotrast).

More recent evidence is the preliminary report from England in 1956 on the apparent increased incidence of leukemias in children following exposure to weak irradiation received through prenatal diagnostic pelvimetry (Stewart, A., Webb, J., Giles, D., and Hewitt, D., Lancet 2: 447, 1956).

Aplastic anemia: It is well known that the atomic bomb victims that survived the blast and were exposed to extensive radiation died with aplastic or hypoplastic bone marrows. The sequence of the morphologic changes in the bone marrow have clearly been described by Liebow, Warren, and DeCoursey (American Journal of Pathology 25: 853, 1949). In experimental animals evaluation of bone marrow radiosensitivity indicates a variation in degree of sensitivity of the hematopoietic elements with the granulocytic and erythroid elements being most sensitive and fat cells and reticulum cells the least sensitive and even quite radioresistant (Bloom, M. A., and Bloom, W., Journal of Laboratory and Clinical Medicine, 32: 654, 1947). However, more recent studies have indicated that erythropoietic elements are definitely less sensitive than granulocytic (Valentine, W. N., and Pearce, M. L., Blood, 7: 1, 1952).

The use of repeated large whole-body irradiation exposures has been studied by Valentine, Pearce, and Lawrence in the cat using 4 exposures of 200 r over a period of 1½ years. Although the exact L. D. 50/30 days is not known, their preliminary work indicated that probably was in the 300 to 350 r range.

Nevertheless, a single dose of 200 r represented a severe hematologic insult. Recovery occurred within 30 days following each exposure with very little detectible marrow damage after four exposures. (Valentine, W. N., Pearce, M. L., and Lawrence, J. S., Blood 7: 14, 1952.)

For a population of 100 million with a lifespan like that of the United States, each absorbed roentgen of whole-body radiation would result in about 6,000 cases of leukemia during their life time, while one-tenth the "maximum permissible dose" of Sr^{90} would result in 35,000 cases. (E. B. Lewis, Leukemia and Ionizing Radiation. Science, 1957, 125 in press.)

GENETIC EFFECTS

H. The nature of genetic effects: Studies, beginning with Mendel, demonstrated that the characteristics of living things were inherited following certain specific laws. Animal-husbandry men and farmers knew most of this but could not interpret the genetics laws properly because of ignorance and lack of information concerning genes and the requirements for expression of inherited characteristics. The germ cells containing only a single set of chromosones which in turn carry only a single set of genes transmit the characteristic of one parent to the child. The child has a double set of chromosones and genes consisting of one set from each parent. Since the characteristic for one parent may be dominant over that of the other, the child will show a mixture of characteristics; some from one parent, some from the other, and some which were common to both parents. Studies with plants, insects, and animals have demonstrated the accuracy of these concepts.

Because there are so many genes and so many variations among the genes for the same characteristic, there is considerable opportunity for variation which in turn permits opportunity to meet changes in the environment. There is still another mechanism which acts as a safeguard to allow the various species to change and thus adapt themselves to severe and marked alterations in the environment. This mechanism is called mutation. It consists of an abrupt, spontaneous change in a gene, producing a change in a recognizable characteristic. Most mutations are detrimental to the species and would be of value

only if there was a considerable change in the environment. It has been estimated that approximately 1 in 10,000 germ cells will undergo such mutation.

Frequency of tangible genetic effects as given by NAS report, i. e., mental defects, epilepsy, congenital malformations, neuromuscular defects, defects in vision or hearing, cutaneous and skeletal defects, or defects in the gastrointestinal or genito-urinary tracts, make up about 4 to 5 percent of all the live births of the United States. Of these about 2 percent are genetically caused. But this is not the natural mutation rate, which also includes lethals, changes in fertility, life span, etc., which are hard to detect and other nonharmful changes (eye color, etc.). Therefore it may be as Muller suggests, more like 1 in every 5, or 20 percent.

Recognized causes for natural mutation are temperature, chemical substances (particularly azone), and radiation. Again based on experiments with insects and animals it has been estimated that radiation equivalent to 30 to 80 r, whole-body dose, will double the normal spontaneous mutation rate. Further it has been demonstrated that the time over which the radiation is received does not affect the mutation rate.

Russell's studies on mutation of seven genes in mice show that about 30 r delivered to immatured germ cells constituted the doubling dose. There is probably not much higher in man, it may even be lower.

Since man exhibits a longer life span than mice and Drosophilia, it is likely that more of the spontaneous mutations are due to background radiation. If it were equal to it (3 r) then the doubling rate would also be 3 r. It is more likely that it is about 3 times as large (10 r) as recommended by the NAS reports.

The frequency of point mutations increases linearly with radiation dosage. In Drosophilia this has been demonstrated for a range from 25 r to 6,000 r. In certain plants this is extended down to 5 r. In mice this has only been tested from 300 to 800 r, but there is no indication that it does not hold outside this range. There is no sign of a threshold below which mutations are not produced, but rather even the lowest are proportionately mutagenic, and all doses are additive or cumulate in effect.

Because gene changes are inherited and because it is very rare for genes to mutate back, the occurrence of a mutation is thereafter inherited until the end of that cell line. Consequently, the effects of mutation accumulate within the population. With random matings these genetic changes become dispersed among the population. If the mutations are detrimental they are likely to cause decreased viability and ultimately death when accumulated in the population to such an extent that both parents transmit the detrimental character to the child. In effect this eliminates the mutant from the population. Ultimately a level is reached whereby for each new mutation arising an old mutant accumulated in the population will be eliminated.

Because of these reasons it has been believed by one group of investigators led by Muller that any increase in radiation can only be harmful and ultimately will lead to degradation and degeneration of the race. However, this will require many generations before such effects could become apparent. A smaller group believes that there are certain inherent safeguards which would protect the species by decreasing mutation rate in response to radiation.

Sturtevant of the California Institute of Technology has calculated that, if the irradiation from fallout increases at its present rate, it will produce some 70 children a year carrying a mutation. This estimate he adds may be too low and, in fact 7,000 may be a better estimate. This has no noticeable impact statistically, that is, about 2 percent (150) will actually show changes from the normal. If compared to the 4 million born yearly and 40,000 defective ones at birth we need not be concerned about the effect of fallout on the future of the people at large or on mankind. Yet if the statistical approach is not used 150 individual newborn children each year will be affected.

Some of the current problems in this field are discussed in the following articles:

Crow, James F., The Estimation of Spontaneous and Radiation-Induced Mutation Rates in Man, from Eugenics Quarterly, vol. 3, page 201, 1956.

Crow, James F., Possible Consequences of an Increased Mutation Rate, from Eugenics Quarterly, in press.

Glass, H. B., The Induction of Mutations with Radiation, talk delivered at International Agency for Peaceful Application of Atomic Energy, Brookhaven National Laboratory, May 15, 1957.

Stern, Curt, Genetics in the Atomic Age, from Eugenics Quarterly, vol. 3, page 131, 1956.
Muller, H. J., Potential Hazards of Radiation, from Excerpta Medica (Amsterdam) in press.
Muller, H. J., Damage from Point Mutations in Relation to Radiation Dose and Biological Conditions, in press.

L. Concepts and definitions for standards pertaining to external radiation effects are covered in Relative Biological Efficiency of Different Ionizing Radiations, John W. Borg, National Bureau of Standards Report 2946, December 30, 1953.

M. Standards for internal radiation effects:

1. Reference is made to the report of the Subcommittee on Toxicity of Internal Emitters as given in Pathologic Effects of Atomic Radiation, National Academy of Sciences—National Research Council publication 452.

Also reference is made to the report Tentative Recommendation of the NCRP for the Maximum Permissible Levels of Radiation to Man, a copy of which is attached.

2. For methods of determining total accumulated doses and dose rates from external radiation, see Doses and Dose Rate Cures, AFSWP Manual No. 99.

N. ———.

SPECIFIC QUESTIONS FOR DISCUSSION

A. All low level effects are not extrapolations from high level effects, (for example see studies by E. Lorenz). Such extrapolations would be hazardous. However, further studies on low-level effects are particularly important since the explosion on March 1, 1954, of an experimental thermonuclear device at the United States Atomic Energy Commission Eniwetok Proving Grounds in the Marshall Islands.

B. There are quite definite distinctions between temporary and permanent (long-term) damages, and between repairable and irrepairable damage. The problem of certain long-term damages may be complicated by sequelae from effects upon tissues other than the one(s) in which the most serious lesion(s) may ultimately appear, as in the development of certain neoplasms. This has been demonstrated in the case of malignant tumors arising in the thymus following irradiation by Kaplan, and may be true also for certain other types of neoplasms arising many years after exposure, as an example, in the skin. While repairable effects are well known, the differential sensitivity of anatomical units of an apparently, morphologically, homogenous tissue may result in incomplete recovery of a sufficient number of components after high doses to result in death of the organism. Recovery of self-replenishing tissues essential to life, such as the bone marrow and small intestine (when the abdomen is the principal site of injury and after supralethal doses of total body radiation) may be sufficiently delayed until sequelae, such as those associated with panhematocytopaenia result in death even though in the case of the bone marrow recovery may still occur if such complications can be controlled.

C. * * *

D. The effects on behavior in Hiroshima and Nagasaki casualities who died during the period of 16 to 69 days is mentioned under Joint Report—Effects of Atomic Radiation on the Brain of Man, Etc., by Shiraki, et al., under X, B-1. There was little evidence of changes in mental posture, personality, and intelligence in those who died during the first 3 months after exposure. Under such conditions the dose level was great enough to cause death from anemia and other factors, but was insufficient to affect directly the brain. Japanese physicians have stated that many patients who survived the bombings have shown no neurological disabilities but have complained of generalized weakness, easy fatigability, and nervousness for years after the bombings.

E. To date we are probably limited for practical purposes in the event of mass casualities due to exposure to ionizing radiation to procedures which will (1) reduce the dose received by such things as shelter, evacuation, clothing, bathing, washing down ships of the fleet, etc.; (2) reduce and combat complications such as burns, indirect injuries from blast effects, and infection; and control the sequelae of panhematocytopaenia, and disturbances in water and electrolyte balance, by procedures in general use for such syndrones from any cause. The possibility of adding to this armamentarium by more specific therapeutic measures, including both humoral and cellular factors appears probable from research to date, but has not been consummated.

F. Unless all radiological factors are reported, and radiation procedures such as fluoroscopy standardized as far as practical, a record of the number of roentgens received by each person during his lifetime would probably not be very meaningful. For example, to record the fact that on a film badge a patient received 10 roentgens, per se, is no more informative than a statement that he was given 10 milliliters of a substance intravenously without indicating the concentration of the solution.

G. The total estimated dose rate to gonads from natural sources of radiation both internal and external is 0.095 roentgens per year. In addition it is estimated that diagnostic radiology contributes 22 percent of the above natural radiation dose. Occupational exposure in radiology and industry adds at least another 1.6 percent of the natural radiation dose. (The Hazard to Man of Nuclear and Allied Radiation, presented to the Lord President of the Council to Parliament by Command of Her Majesty, June 1956.) H. (The numbering of the questions skips from H to J).

J. * * *

K. Radioiodine acts principally on the thyroid, but a possible relationship to leukopenia and anemia has been suggested. The doses and expected effects are as follows:

(*a*) 1 or 2 milliocuries I^{131}: This is the lowest amount that will cause transient alteration of physiological activity of the thyroid. No recognizable histologic changes would be expected.

(*b*) 10 to 15 millicuries I^{131}: This amount will cause a mild transient decrease of thyroid activity, probably detectable only by laboratory tests. The depression may last a few months. Histologic alterations, if any, would be in the form of mild fibrosis and slight los of foilicular epithelium.

(*c*) 35 to 75 millicuries I^{131}: Usually given in fractional doses, this total amount can be expected to produce definite clinical hypothyroid state for between 6 and 12 months. Histologically, there would be varying degrees of fibrosis and follicle destruction.

(*d*) Two courses of 35 to 75 millicuries I^{131} can be expected to produce almost complete cessation of thyroid function with severe myxedema. The duration of the myxedema cannot be predicted, as the patients tend to develop thyroid activity over the course of a few years. Histologically, one would expect virtually complete fibrosis of thyroid with a few surviving distorted epithelial cells and possibly a few distorted follicles. Eventually, some regeneration of follicles might occur. Even though there may be widespread destruction of thyroid, the parathyroids are unaffected.

(*e*) 1,200 to 1,500 millicuries: This total amount has been given over a period of several years to a few patients. Leukopenia and/or anemia has sometimes developed and been attributed to the radiation effect or circulating I^{131}, but there is no proof that the hematologic changes were due to I^{131}. Amenorrhea has been reported, but there is no proof it was the result of I^{131}.

Cs^{137}: There is no evidence so far that Cs^{137} has any unusual biological properties. It does not seem to localize in bone.

C^{14}: This is eliminated fairly rapidly (about 97 percent in 3 or 4 days) from the body, largely as CO_2. It does not localize in bone.

L. * * *

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Biographical Sketches of Witnesses Who Contributed to Statement by Armed Forces Institute of Pathology

ELSON BOWMAN HELWIG

Birth: March 5, 1907, Pierceton, Ind.

High school education: Warsaw Indiana High School, graduation 1925.

Preprofessional education: Purdue University, Lafayette, Ind., 1925–27.

Professional education: Indiana University Medical School, Bloomington, Indianapolis, Ind., B. S. June 1930, M. D. June 1932.

Internship: City Hospital, Indianapolis, Ind., rotating service 1932–33.

Residencies: City Hospital, Indianapolis, pathology, resident 1933–34; Institute of Pathology, Western Reserve University, Cleveland, Ohio, pathology, assistant resident 1934–35; City Hospital, Cleveland, Ohio, pathology, resident 1935–36; New England Deaconess Hospital, Boston, Mass., assistant pathologist, 1936–39.

Certified by the American Board of Pathology: 1938.

Membership in Professional Societies: College of American Pathologists, Washington Pathologic Society, American Association of Pathologists & Bacteriologists, American Society of Clinical Pathologists, American Association for Cancer Research, Massachusetts Medical Society, Baltimore-Washington Dermatological Society, American Academy of Dermatology and Syphilology, International Academy Pathology.

Teaching associations and appointments with professional schools: Indiana University School of Medicine, assistant surgeon pathology, 1933–34: Western Reserve University Medical School, demonstrator, pathology, 1934–36; Washington University School of Medicine, instructor, pathology, 1939–42; Washington University School of Medicine, assistant professor pathology, 1946–47; George Washington University School of Medicine, professorial lecturer, 1947.

Military service: Army Medical Museum, 3 months, 1942; Chief of Laboratory Service, Bruns General Hospital, 1934; Chief of Pathology Branch and executive officer, 18th Medical General Laboratory, and consultant in pathology, Pacific Ocean area, 1944–45.

Present occupation: Senior pathologist at the Armed Forces Institute of Pathology; Chief of the Division of Pathology; Chief of the Pathology Branch; Chief of Derman and gastro-intestinal pathology.

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SHERWOOD M. REICHARD

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Research

1949–53: With Prof. Albert S. Gordon, NYU: endocrine influences upon the phagocytic incorporation of colloidal thorium by the reticuloendothelial system.

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1955 (May-Oct.): (Interim position): waiting for commission in Army). Research Associate, with Dr. Raymond Klein, Brookhaven: D-amino acid oxidase purification and extraction—inactivation by x-irradiation, its prevention by certain aromatic acids.

1955–present: 1/Lt, U. S. Army, Armed Forces Institute of Pathology, Dept. of Radiobiology, Washington 25, D. C., with Col. Carl F. Tessmer. Radiation activation of tyrosinase, quantitation and correlation with pathological changes in skin (C^{14} studies); tyrosinase activity in melanotic tumors; x-irradiation and phagocytosis of the RES; Reticulo-endothelial protection factors in trauma.

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Papers in preparation

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1920–22: College of Charleston, Charleston, S. C.

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1932–33: Intern, American Hospital, Paris; part time Institute du Cancer, University Paris (with Roussy and Verne; tissue culture CNS).

1933–34: Director of Laboratories, State Sanatorium, Wallum Lake, R. I.

1934–35: Fellow in Neurology and Neurosurgery, Montreal Neurological Institute (with Penfield), McGill University (M. Sc.).

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1936–42: Assistant clinical professor neurology and lecturer in neuroanatomy, University of California, School of Medicine, San Francisco and Berkeley.

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Representative HOLIFIELD. Our next witness is Dr. Austin M. Brues, of the Argonne National Laboratory, director of the Biological and Medical Research Division since 1946, and delegate to the U. N. Radiation Committee.

All right, Dr. Brues.

STATEMENT OF DR. AUSTIN BRUES, DIRECTOR, BIOLOGICAL AND MEDICAL RESEARCH DIVISION, ARGONNE NATIONAL LABORATORY [1]

Dr. BRUES. Thank you, Mr. Chairman.

I do have a short prepared statement which I intend to read in its entirety.

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Representative HOLIFIELD. All right.

Dr. BRUES. I want to speak chiefly concerning the philosophy of setting and determining the permissible levels which Dr. Taylor spoke of earlier this morning, and what the true basis of our understanding of these is.

The presently accepted safe levels of radiation and of radioisotope incorporation are based on a long history of clinical observation and experimental research. These levels have been determined on the basis of making the most pessimistic assumptions where knowledge is lacking and then introducing a factor of safety.

Where direct observations on human beings or suitable animals have been at hand, the practice has been to divide those levels which produce any detectable effects by 10 to arrive at a permissible level. It was on this basis that the permissible daily X-ray exposure of 0.2 roentgen to the whole body was reduced many years ago to 0.1 roentgen, and then, as a result of some further work which was done during the Manhattan District days, particularly having to do with the production of sperm in dogs given one-half roentgen a day, which showed dogs had some changes in the rate at which they produced a sperm, it was considered one-twentieth of a roentgen a day would be a safer dose.

The question then came up as to whether these levels had to be adhered to each day or whether one might not receive a week's dosage on Monday morning without any further effect than that incurred by spreading it through the week. While an acutely dangerous dose of radiation—say 500 roentgens—is less toxic if spread out over a week owing to the rapid recovery of the blood-forming tissues, there seemed to be good experimental evidence that the late consequences of low doses were rather independent of time, and so three-tenths of a roentgen per week was accepted. It seems quite likely that the whole yearly quota of 15 roentgens—which in itself produce no obvious effects—might as well be incurred on a single day, but three-tenths per week appears to be more practical, except for special cases such as might arise under civilian defense conditions, where a calculated risk might be acceptable.

That sort of thing has also been allowed for.

Ingestion or inhalation of radioactive substances presents a different problem. These sources of radiation may become concentrated in certain tissues and organs, and the greater part of the radiation energy, depending on type, may be given locally. The most striking example of this is the concentration of radioactive iodine in the thyroid gland, where half of the dose may be deposited in one one-thousandth of the body. We do not, unfortunately, for purposes of cancer treatment, know of any other such striking case of an extreme localization.

There have been two ways of solving this question. One has been to calculate the radiation dose in the "critical organ," that is, the organ with the highest radioactive concentration, and then to set levels of exposure such that the equivalent of three-tenths roentgen a week will not be exceeded. The other has been—and this is used where the bony tissues receive the highest dose—to compare the possible damage with that produced by radium in the human skeleton, since we have knowledge derived directly from the histories of persons who have been poisoned by radium through industrial exposure in the watch dial painting business or through administration of

radium as a drug in the days, 25 to 30 years ago, when it was thought that radium might be beneficial in certain conditions for which there was no known effective treatment.

Since no damage had been observed in patients who retained less than 1 microcurie of radium in the skeleton, about the amount in a radioactive watch, this was again divided by 10 and one-tenth microcurie was established as a permissible amount of radium. To this day, no detrimental effects have been seen in persons containing this amount of radium.

Since the preparations used to paint luminous watch dials and for some medical uses contained considerable amounts of other radioactive elements—specifically mesothorium—it has been suggested that pure radium may be less toxic than indicated here. This point is not settled, and a search is being made for other persons who may contain abnormal amounts of radium in order to improve our knowledge. In particular, it is becoming clear that a good number of persons may harbor more than 1 microcurie without detectable harm of any sort, and that the proportion who do suffer for a given amount is lower than was believed.

Since the first cases seen, and the majority, were found out because they had complaints which directed the attention of physicians to them, we see a selected group of people who met with the worst result; the well ones are much less likely to come to our attention.

This, again, I think, introduces somewhat a factor of safety in the question of how much radium is likely to produce serious effects on the human being.

These radium levels have been transferred to other radioactive materials as a result of comparing effects of radium on animals against those of plutonium or radioactive strontium. Plutonium turns out to be somewhat more toxic than would be expected from physical calculations of the radiation to bone, and this is apparently because plutonium is deposited near those cells which are active in bone growth.

Radioactive strontium 90 has been determined to be one-tenth or less as likely to produce bone tumors as radium for a given number of microcuries. On this basis, 1 microcurie of strontium 90 is considered as the equivalent of one-tenth microcurie of radium and, therefore, is designated as the maximum permissible level.

These levels were employed very successfully in the atomic-bomb project during wartime. Most of the workers remained very far below the permissible levels.

If you set up a level which is not to be exceeded, it happens, administratively, that things work out so that people get very much less.

There is the story of one individual on the project who attempted to receive his 10th roentgen per day because that is what he thought he was supposed to do. But, in general, nothing like this happened.

For practical purposes it is necessary to determine many more things than just the safe level of body content. We must also translate this into the amount which can safely exist in the air breathed and in the food and water ingested, in order to regulate these concentrations at a level which will not permit an excessive load to exist in the body. These are, then, the MPC's, or maximum permissible concentrations. This means we must use our best information as to how much is retained in the body from inhalation and from the digestive tract, and how fast it is lost from the body by excretory processes.

Many of these things have to be decided upon before the enormous amount of experimental work required for an exact answer can be carried out. There is no time here to discuss all this, but I can say that those committees shouldered with responsibility for such decisions always use the strictest possible assumptions, and, since several separate assumptions must be made—for example, how much in the air gets into the lung, how much in the lung is kept there until it gets into the circulation, how much of that is deposited, and how fast it is lost from the organ—as well as the relative effects of types of radiations from different elements, each of these considered in the worst light, we end up by multiplying a number of different factors of safety and are almost certain to come out with a level much lower than the correct one.

To give a few examples:

When tritium was first under consideration, it was noted that it has a remarkably short-range beta radiation, and nothing like it had been studied experimentally. So a factor of safety of 10 was introduced until it was shown that it acts about the same as the more familiar radiations, when this factor could be thrown out. Similarly, the strontium and radium levels were based on an early assumpion that they are lost from the bone according to a very slow process, which was measured on patients and animals a long time after its acquisition. This led to very low levels being recommended in water. It has since become known that loss occurs very rapidly at first, so that it requires about 10 times as much taken in to maintain a given level. The MPC's in this case have not yet been changed until complete study of the problem can be made, although the evidence is now fairly clear.

In another instance, a stringent level of radium in water was suggested unofficially, and we found that it was actually less than that in the drinking water of our laboratory. Had this been adopted, we would have been required to distill our own domestic supply before we could be permitted to let it flow off the grounds.

Of course, radioactive materials, as you have probably heard in the last few days, because of their special nature and the degree of development of our instrumentation, can be detected in relatively much smaller amounts than almost any other toxic material. This may be a large part of the reason for the disproportionate public concern about radioactivity relative to other noxious things.

As you are aware, there has been a general lowering of levels recently, since artifically produced radioactivity has become wider in its scope.

Here, we have to keep two things quite distinct. First is the problem of genetic effects, which will be discussed by others. The special features of these is that they seem to be produced without threshold: that is, any small amount of radiation will produce its proportion of changed genes; and that almost all of these are hidden and are perpetuated through generations till they come together accidentally through interbreeding. Thus, very stringent levels are recommended, but they do not refer to any individual but to the whole population; thus an average figure for the whole population is all that is to be looked for.

The other is concerned with the matter that we must not only consider, as was the basis of the original levels, a selected group of in-

dustrially exposed persons, but also many persons outside this group who might be close to installations where exposures could occur.

One asks, of course, why if a level is safe for one group, it is not for another. There are several reasons for this, none complete in itself. One is that the occupationally exposed group are selected, do their work voluntarily, are under medical control and are monitored. Another is that persons not in the atomic energy business may be in other fields of work which have their own peculiar hazards. Still another may be that there are more chances for an overexposure to occur. So that we might set the levels so that a considerable "overexposure," on that basis, would still not be an overexposure in the sense that it get to a level which would be within the potential danger zone. For these and other reasons, in one sense or another philosophical, we have adopted another safety factor of 10.

Mr. RAMEY. On our last point there, about your safety factor of 10 with respect to strontium 90, would the fact it applies mostly to the takeup of strontium 90 as it affects persons that it would be more as it applies to children, and therefore a lower factor when you go from an occupational group to a population group to take into account the bone-forming period?

Dr. BRUES. Well, this question has been raised. Actually I do not know of evidence that the skeleton of the child is more sensitive, except with respect to the fact that if one starts as a child and continues to an adult, he puts more of the material away. This, I think, has already been taken into consideration. We could still have more evidence on this, but data I have seen does not suggest the child at these low levels, where not stunting his growth, is going to show any more results than certain total amounts for others.

Representative HOLIFIELD. It is a fact that the bones of a child are growing and accumulating more cells at a faster rate of cell growth than the adult, is he not?

Dr. BRUES. That is true, yes; and on a given intake level, a larger total will be evident.

Another consideration which has led to extra safety is that of the fluctuating level of exposure. Where we have set conditions for exposure to external radiation we have allowed for such fluctuations. It seems equally reasonable for the level to say, radioactive strontium in water to exceed the MPC by 7 times 1 day a week; or for the point of disposal in a highly polluted river to exceed the MPC so long as it is diluted out before it reaches a point where it would conceivably be ingested—remembering also, that the MPC is based on the assumption of continuous intake for a lifetime. The same situation applies to shifting winds around a stack. For exadministrative reasons, it is therefore highly likely that conditions will be set which are much more stringent than those leading to a maximum possible concentration in personnel. It is most important to remember that that is what we are really concerned with, and that no legal culpability should be involved in an occasional fluctuation in the environment above that which would be one-tenth or one-hundredth of a dangerous level but only if it were kept up indefinitely.

The whole basis of the concept of a permissible amount, or level, by the way, rests on the assumption that there is a threshold; that is, that no harm will be done by smaller amounts. In genetics, we have reason to doubt that there is a threshold at all, so that the total popula-

tion average of exposure is set so low that it falls close to the natural variations in the natural radiation background.

Where the question is applied to other effects of radiation, such as longevity or cancer, we do not know whether they have thresholds or not. It has been suggested that they do not, but on the basis of very scanty evidence so far, and in no case is there information much below 100 r; and there are also good reasons from what we know about the nature of cancer to suspect that the hazard goes down faster than the insulating agent. An animal experiment to guarantee the existence of a human threshold below suggested off-site MPC's would be a prodigious undertaking and would drain off much of our talent from work which is really more basic to the problem. It would, moreover, detract both talent and public attention from problems of the same sort that seem, to me at least, as urgent.

For instance, millions of Americans now living will die of cancer of the lung due to something in the environment that we did not have a few decades ago. I once made a calculation by exactly the same means as are used in the calculations of MPC's, comparing lung cancer with radium cancer, and derived an MPC—occupational criteria—of 2.4 cigarettes a day. An off-site MPC would be 1 every 4 days. The only assumption made here was that cigarettes are the causative agent. If it is city smoke, this would have to be reduced in a similar proportion before the criteria used in determining permissible levels of radioactive substances would find it allowable.

Senator ANDERSON. What year would become a basis for this new item which has come into the picture? You say something about decades. How far back?

Dr. BRUES. These figures, of course, vary from place to place, and they have been coming up more slowly in the female than in the male. But in general there has been at least a tenfold increase in lung cancer since 1900, in the rates for age since 1910 up to the decade 1940–50. This is apparently still rising at a considerable rate, and, as I say, people are very much concerned about this problem.

Senator ANDERSON. Particularly with all the millions of dollars we are spending on cancer research. The more we study it, the worse it appears to get.

Dr. BRUES. This may be repeating my colleague slightly, but I will mention it again.

If we are to settle the question of threshold satisfactorily, I would say that we should carry out expanded studies on large populations of animals, but not rely on this to the extent of reducing the amount of basic work which will probably lead us sooner to a clear answer. I refer to many things, but chiefly studies on the nature and origin of cancer, the effects of radiation on cells, the nature of the aging process—for example, why a mouse lives little more than four score weeks and ten—and broad studies of medical and population statistics in relation to natural radiation.

Along with this are the whole unexplored fields within the medical and biological sciences, any one of which might turn out to be crucial to the radiation problem; recruiting and training good talent; and communication of scientific research findings.

As one who sits on various committees to discuss and, we hope, solve these problems, I am also impressed with the danger that more and

more of the best talent and time for the imaginative approach to these questions may be drawn away from the work and thought that they ought to be producing, into more and more debate over the same scanty knowledge.

May I just conclude with what might be a scientific parable, by pointing up the potential difficulties of the whole problem from an experiment done by the late Dr. Egon Lorenz.

Dr. Lorenz carried out the lowest-level experiment in chronic irradiation that has been done, giving mice a little over 0.1 roentgen daily throughout their life. He found, and thus confirmed an earlier experiment, that the irradiated mice developed more leukemias than those that were not irradiated, but that their average life span was almost 10 percent longer.

What a mouse would do in this case if he had a free choice, I am not sure.

Representative HOLIFIELD. Thank you very much, Dr. Brues, for your illuminating discussion.

Are there any questions?

Senator BRICKER. You would not want to conclude from that, if a human being was given 1 roentgen a day for his life, he would live 10 percent longer, would you, Dr. Brues?

Dr. BRUES. No, sir. Part of the parable was to say that I do not like to extrapolate animal experiments to man until they have reached a fairly good degree of ramification.

Senator BRICKER. I would not want to give him his free choice in that case.

Representative HOLIFIELD. The chart that Dr. Friedell gave in his statement showed that a lethal dose of 50 percent would apply to dogs, 350 roentgens; mice, 450 roentgens; monkeys, 500 roentgens. So that seems to be the nearest reaction as between your permissible dose of 400 roentgens to animals you are experimenting on. Is that right?

Dr. BRUES. That is right.

We do not know that the acute results run into the same proportions as late chronic effects.

Representative HOLIFIELD. There must have been some reason why they were in the same dose range, rather than rabbits, at 800, bacteria at 100,000 roentgens.

Dr. BRUES. The mammals do run, as far as acute kill goes, between perhaps 300 and 900. There is that degree of variation between the species, and this is just the amount that will kill them in a couple of weeks.

Representative HOLIFIELD. But you draw no parallel between setting the lethal dose of roentgens for man in that category?

Dr. BRUES. I would be afraid to.

Representative HOLIFIELD. Are there any further questions?

Thank you very much.

We will adjourn now until 2 o'clock, when we will have Dr. E. P. Cronkite, Dr. Edward Lewis, and Dr. Shields Warren as our witnesses this afternoon.

(Whereupon, at 12:45 p. m., the committee was recessed, to reconvene at 2 p. m., of the same day.)

Dr. CRONKITE. I think there are many possible answers. It has been abundantly proved for example that benzol and various other industrial poisons are also capable of inducing leukemia in experimental animals and presumably also man. If my memory does not fail me, and I could document this, in the lithographing industry at one time there were a few cases of leukemia presumably induced by overexposure to benzol. Certainly, many of the things that are used in medicine, where a calculated risk is deliberately taken, for the immediate welfare of a patient, occasionally one gets into trouble with drugs.

There are many things I could think of. The heavy metals. There are numerous things in the industrial life of today that can be toxic and can produce the same things that radiation does.

Representative COLE. I was impressed by an observation made by a witness this morning which, as I recall, was to the effect that since toxicity from radiation is a condition that is readily detectable by reason of our devices, that there might be an inclination to attribute the biological damage to that toxicity which is identifiable, rather than to another toxicity which might exist but which could not be so readily identified.

Do you subscribe to that general observation?

Dr. CRONKITE. I certainly do, Mr. Cole. I think you have expressed it better than I can.

Senator BRICKER. Mr. Chairman, I have just one question.

What is the ratio of body exposure to radiation from the cosmic rays and from the background material from the earth radiation?

Dr. CRONKITE. I am sorry, I did not follow you.

Senator BRICKER. The ratio that the human body is exposed to from the cosmic rays coming from the atmosphere and that radiation to which we are exposed from the materials of the earth.

Dr. CRONKITE. I am fairly confident that it is larger from cosmic radiation than from the earth, but I would have to defer to somebody who has personally investigated this field, which I have not done.

Representative HOLIFIELD. Thank you very much, Doctor Cronkite.

Our next witness is Dr. Edward Lewis. He is a professor of biology at the California Institute of Technology, and his present work is on the nature of the gene and mutational processes. He has a notable scientific background, and we will be glad to hear from Dr. Lewis at this time.

STATEMENT OF DR. EDWARD LEWIS, CALIFORNIA INSTITUTE OF TECHNOLOGY[1]

Dr. LEWIS. Mr. Chairman, with your permission I would like to use the podium.

Representative HOLIFIELD. You may proceed.

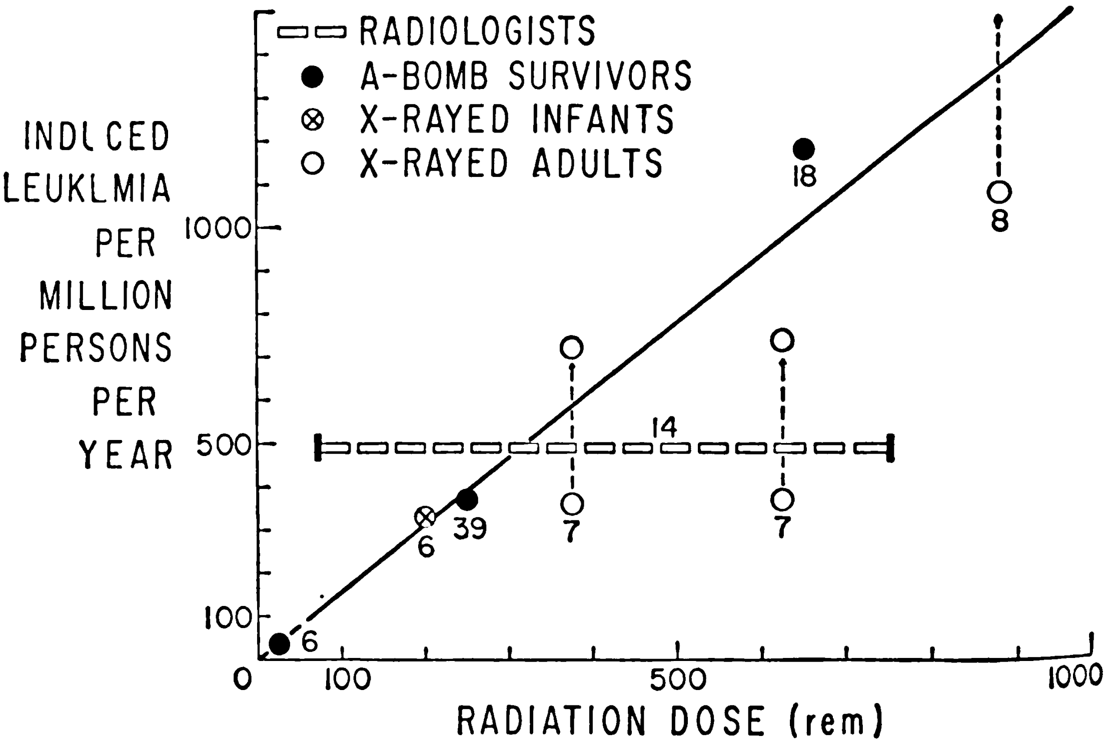
Dr. LEWIS. Mr. Chairman, I would like to thank you for this opportunity to testify. I will confine my remarks to the subject of

[1] Date and place of birth: May 20, 1918, Wilkes-Barre, Pa. Education: B. A., University of Minnesota, 1939; Ph. D., California Institute of Technology, 1942. Captain in USAF, 1942–46 (specialty—meteorology and oceanography). Fellow of Rockefeller Foundation, 1948–49; Cambridge, England. Present position: Professor of biology, California Institute of Technology, Pasadena, Calif. Present work: Nature of the gene and of the mutation process. Member of the Genetics Society of America and the American Society of Naturalists. (Submitted by witness.)

leukemia. I have been asked to do this, and I want to point out that in doing so I do not wish to imply that I think that leukemia is the most important effect of radiation on man. I think in fact possibly the genetic effects may be more important. There may also be other malignant diseases that are more important than leukemia with respect to ionizing radiation.

However, the reason that I am stressing leukemia today is that we have rather good data and rather good evidence on leukemia as compared to data on other effects on man from ionizing radiation and it is this evidence I would like to go into today.

I would like to present this evidence by means of this chart. A detailed account of this evidence has been recently published in Science (vol. 125, pp. 965–972).



Summary of incidences of induced leukemia among various groups of persons subjected to ionizing radiations. The numbers under the circles refer to the number of cases of leukemia that are estimated to have resulted from the radiation. "X-rayed infants" refers to children treated for thymic enlargement. "X-rayed adults" refers to patients with ankylosing spondylitis. (References to the original literature and methods of estimating incidence of radiation-induced leukemia and radiation dose are contained in Science, vol. 125, pp. 965–872. May 17, 1957.)

This chart shows radiation dose along the bottom in the rem unit which Dr. Taylor talked about this morning, essentially the same as the roentgen unit. We use it here because we are going to include some information on atomic bomb survivors whose total irradiation included a percentage due to neutrons, possibly 10 to 20 percent.

Along here we have induced leukemia per million persons per year. The first thing we might consider are the circles. These are people who have died of leukemia as a result of a sudden dose of radiation. We all know about the atom bomb survivors receiving varying amounts of radiation in Hiroshima and Nagasaki as a result of the August 1945 bursts. These points are shown in blue. The largest

number we have is shown here as 39 persons estimated to have died of leukemia as a result of radiation. There were actually in a certain zone in these cities 41 persons who died of leukemia, and who were estimated to have obtained approximately 250 rem units. Of the 41, 39 are those we would estimate died from the radiation. The remaining 2 would have been expected to die as a result of the natural leukemia incidence within the population. This result is based on some 14.000 people. The period of time is almost 8 years. (This is a study from 1948 to 1955—September of 1955—and that is a 7.8 year period).

Representative COLE. Mr. Chairman, in order that we might have a better understanding of the observations which the chart discloses, may I inquire if this chart reflects the studies on all of the people affected by both the atom weapons or 1 of them or a segment of 1 of them? Thirty-nine out of perhaps 5,000 persons might be significant. If it is 39 out of 500,000 it would be less significant. In order to really evaluate and appreciate the significance of the chart I think we should know the extent or the area included in the observation.

Dr. LEWIS. Thirty-nine of the 14,000 in this particular case, sir, is the number of cases of leukemia in a certain zone in both cities—a certain area, namely in this particular case, extending from 1,000 to 1,500 meters from the point on the ground under the bursts. The combined total number of people in this area in both cities was 14,000, approximately, from census estimates in 1950.

I might add that these data have been published by other investigators and collected by a great number of people. The only thing that we do here is to relate incidence of leukemia to dosage. This has not been done before for the reason that the Atomic Bomb Casualty Commission did not have the doses for so relating the incidence of leukemia.

There are 18 cases of leukemia which have arisen in the zone from zero to 1,000 meters from the point on the ground under the aerial bursts in Hiroshima and Nagasaki. There were only approximately 1,800 people who survived in that zone and among these the 18 cases of leukemia accumulated over the 7.8 years. This is about a 1 percent incidence of leukemia. The average absorbed dose in this case is estimated to be about 650 rem.

This point down here represents six people, a very small number of persons as far as our purposes here are concerned, which are to try to relate the dose to the incidence. There were in fact 10 persons who have died already in this region from leukemia, among approximately 23,000 people who were exposed in this dose range. That is, the combined total in the 2 cities of Hiroshima and Nagasaki was 23,000 persons who were beyond the 1,500 meter point and who were between 1,500 meters and 2,000 meters.

Of the 10 persons who died of leukemia, 4 would have been expected to have died on the basis of the spontaneous incidence. That leaves six, which is the expectation for the number who have died from A-bomb radiation. That is a low number and is subject to considerable error. The average absorbed dose in this region is estimated to be only 25 rem, and the maximum possible dose in this region was 100 rem.

I call your attention to the fact that we haven't much information in this part of the curve and yet that is the part of the curve that we are interested in here because we are considering small amounts of radiation.

I will only quickly point out that there have been children who have received a rather large dose of radiation, some averaging possibly anywhere between 100 and 300 of these units. They have an increased rate of leukemia which is statistically significant. There were 7 cases of leukemia in a group of some 1,400 children in this case. These 7 have developed leukemia after having been X-rayed as infants for a chest condition; 6 of these is the number that we would estimate were due to radiation, because at best only less than 1 is expected from the natural incidence of leukemia. I have been referring to a study by Dr. Simpson and associates.

A study is being made in Great Britain by Dr. Court Brown and colleagues of X-rayed adult males who had been treated for a serious spinal abnormality which is alleviated to some extent by this treatment.

In this case we have in the orange circles different treatments given to 11,287 male patients in Great Britain. These are the numbers of individuals, and this [indicating] would be the rate of leukemia. It is a significantly increased rate. They were irradiated only in partial body form to the spinal area, and seemed to develop only the kind of leukemia that stems from the bone marrow and hence it is possible that the total leukemia rate per unit of radiation dose would be higher by a factor of 2 (shown by the dashed vertical lines).

As I said, these are acute doses of radiation—sudden doses. We are interested in slow chronic radiation exposure. We have some evidence on this which has been accumulated again by a number of investigators. I refer to a group of occupationally exposed persons, namely radiologists. The period of time that we are going to talk about is from 1938 to 1952, inclusive. It is estimated that 14 radiologists died of radiation-induced leukemia out of 17 who died of leukemia. That is, three might have been expected according to the spontaneous incidence figures. This is corrected for the fact that we would expect radiologists to have a higher rate of leukemia than the United States white male population owing to differences in age composition.

The long range here means that we do not know what dose radiologists got because, as we know, they got it as a chronic exposure over many years.

I point out that we estimate that somewhere around 250 to 300 r. units or rem units would be the accumulated dose for their mean period of occupational exposure and that period is about 25 years, as it turns out.

Representative COLE. Mr. Chairman, may I inquire with respect to the radiologists over a period of 14 years, from 1938 to 1952? You say that 14 out of 17 radiologists who died from leukemia were traceable to their work. That is a total of 17 radiologists who died as a result of leukemia out of how many radiologists?

Dr. LEWIS. 1,860, sir. That population developed from a figure of about 1,300 in 1938 and has increased by 1952 to about 2,500. But the average for that period was 1,860 radiologists. Also, only radiologists who were at ages 35 to 74, inclusive, during the 1938–52 period are considered here.

I want to point out now that one can draw various curves to express these data. I have drawn here a straight-line curve which would say that the incidence of leukemia is directly proportional to the dose. I

feel that the evidence supports this to some extent in the high-dose region. In the low-dose region here, there is a dashed line, and there are only six individuals on which to say anything. The point here, however, is that in the absence of any other information it seems to me—this is my personal opinion—that the only prudent course is to assume that a straight-line relationship holds here as well as elsewhere in the higher dose region.

It may be that there is a threshold—that is, a dose below which leukemia will not develop. However, we can say safely, I think, that if there is a threshold dose it must be below 100 r. The reason for saying that is that in the region below 100 r. you would not expect to have gotten the 6 cases of leukemia as a result of chance more than 1 in 50 times.

I would like to point out one figure that we are very sure of, and that is simply the spontaneous incidence of leukemia in this country. This is 10,000 deaths from leukemia per year in the United States in 1954. It is actually 10,500, but in round numbers 10,000 is the number who die of leukemia in this country at the present time.

If we use this straight line and assume it is a straight line in the low-dose regions—as far as I can see there is little reason to believe that this is not the correct assumption in this region—then we can make some simple calculations, making use of that line. These calculations come out as follows:

One thousand deaths from leukemia per year is what we would expect from natural background radiation. The natural background radiations include cosmic rays, and radiation from rocks, buildings, and the radioactive isotopes in the human body. We receive a dose rate of 100 millirem, or one-tenth of an r. unit, per year from such sources. That is approximate. It varies somewhat from place to place and from time to time and therefore it is not quite clear what the precise figure is.

We see from this that if the straight-line relation holds, there are a fair number of cases actually attributable to the natural radiation. There are some other figures here that are of interest. The figure that we were given of 14 million rem per million people per generation this morning by Dr. Taylor would work out to be approximately five-tenths of a rem per year—not quite—0.47 rem per year. That would be the new public's permissible dose that was mentioned, I believe, particularly with the gonadal dose in mind. But you can't avoid that dose for the whole body as well in most procedures, so that such a dose leads to a sizable number of leukemia cases compared to the spontaneous incidence.

Representative HOLIFIELD. What does that lead to? What would be the number that five would lead to? Would it be 5 times 1,000?

Dr. LEWIS. Do you mean this? [indicating], namely 5,000 cases per year.

Representative HOLIFIELD. Yes. Assuming that 0.5 r. per year is the burden of your argument that it would increase the 1,000 cases to 5,000 per year.

Dr. LEWIS. It would add the 5,000 to the 10,000 total. The new proposed permissible dose for the United States public, would lead to 5,000 cases per year on this calculation, of which 1,000 cases per year would be due to the natural background. So 4,000 cases per year would be the added rate.

As far as fallout is concerned, which is the relevant thing today, I think 0.001 r. is a conservative rate per year that one can estimate we have at the present time reached on the basis of an estimate that was given to the Genetics Committee of the National Academy of Sciences; namely, that the United States now gets one-tenth of an r. per generation—per 30 years—from fallout. One-tenth of an r. per 30 years corresponds to three one-thousandths of an r. per year. I have not used 0.003 because it is possible that the whole body absorption dose would be less than this. So we take 1 milliroentgen (0.001 r.) per year as a conservative rate. Then if we reach this level and maintain it continuously, that leads to 10 as the number of deaths from leukemia per year from fallout sources. We have not had this exposure long enough to make it 10 per year as yet. This exposure would have to go on for 60 years. That sounds like a long period of time. However, radiation from strontium 90 in the bones will help to contribute at least this high a dose rate for quite a while to come because of the retention of strontium 90 in the bones and because of its long half-life (28 years).

This particular estimate of 10 deaths from leukemia per year at the present fallout rate would not be this high at the present moment in the United States. I do not think it would be higher than 1 to 3 deaths per year at the present time from fallout that has accumulated so far. In terms of our population that is a very minute fraction of the population—an exceedingly minute fraction—but after all, it does correspond to somebody.

Thank you.

Representative HOLIFIELD. Thank you very much, sir.

Senator ANDERSON. Did you say if a threshold exists at all it must be below 100 r. for the Hiroshima-Nagaski victims?

Dr. LEWIS. Yes, sir.

Senator ANDERSON. Is that not about the lowest we have had yet on that?

Dr. LEWIS. I think it is for human beings. There are data indicating that in mice such a dose would be still lower.

Senator ANDERSON. I am talking about human beings.

Dr. LEWIS. Yes.

Representative HOLIFIELD. In the concluding part of your statement you say that if the present population of the United States were to be constantly exposed to 100 sunshine units of strontium 90, the prediction calculated in this way is that 500 to 1,000 cases of leukemia would occur annually from this source alone.

The direct proportionality law further predicts that constant exposure to 1 sunshine unit of strontium 90 would be capable of producing from 5 to 10 cases of leukemia annually in the United States population. You have illustrated that by the chart.

So the position that you take, then, is that any radiation would have an effect and that therefore there is a threshold.

Dr. LEWIS. Is not a threshold.

Representative HOLIFIELD. Is not a threshold, I should say.

Dr. LEWIS. That is right. The threshold concept would say that you would not get any leukemia at all until you reach, say 500 r., which in a sense was the assumption when it was thought you could safely accumulate radiation as an occupational worker at a rate of 15 r. per year. Now we have more information that says, no, the threshold

dose had better be put well below 500 r. I would say we must put it well below 100 r.; in fact, I doubt that a threshold exists.

As far as I can see from analogy with phenomena of genetics, which is my field, there is a possible theoretical basis for predicting that there would be no threshold, namely, if leukemia is due to a somatic mutation. That is the interest of geneticists in this disease. However, these calculations do not assume that leukemia is due to a mutation. It does not matter what leukemia is due to; if this line continues as a straight line to zero then these calculations are valid.

Representative HOLIFIELD. Are there any further questions?

If not, thank you, Dr. Lewis.

(A statement and an article entitled "Leukemia and Ionizing Radiation," by Dr. Edward Lewis, follows:)

STATEMENT BY E. B. LEWIS, JUNE 3, 1957

Exposure of human beings to radioactive fallout is expected to have two types of biological effects: (1) genetic effects on the descendants of the exposed individuals, and (2) direct effects on the exposed individuals themselves. The present testimony is restricted to considering one of the direct effects; namely, the induction of a specific malignant disease, leukemia.

In recent years, a number of investigators have been making careful followup studies of persons who are known to have been exposed to man-made sources of radiation. These studies have provided us with abundant evidence that radiation induces leukemia in man. The following four groups of people have been the principal ones investigated: (1) survivors of the atomic bomb bursts over Hiroshima and Nagasaki; (2) patients irradiated with X-rays for the purpose of alleviating a spinal abnormality (ankylosing syondylitis); (3) children irradiated with X-rays as infants for the purpose of alleviating an enlarged thymus gland; and (4) radiologists, who, of course, are occupationally exposed to ionizing radiations.

For each of the above four groups of persons, it is possible to make estimates of the doses of radiation which they received and then to relate such estimates to the number of cases of leukemia that developed subsequent to the irradiation. When this is done, it is found that the incidence of the disease tends to vary in direct proportion to the dose of radiation. That is, doubling the dose tends to double the number of people who will develop radiation-induced leukemia, other factors being equal.

The Japanese survivors and the X-rayed patients were subjected to sudden doses of radiation, whereas the radiation from current levels of radioactive fallout is expected to be delivered gradually over many years with only a very small amount occurring at any one instant. How effective, then, is chronic irradiation in producing leukemia? Radiologists have received their radiation as a chronic occupational exposure extending over many years and in relatively small amounts at any one time. Yet, radiologists die of leukemia at a rate which is about five times that expected if they had received no occupational exposure to radiation. Also, radiologists seem to have about the same chance of developing leukemia, after a given dose of radiation, as do the survivors of atom-bomb radiation or the patients treated with X-rays.

The above findings suggest that the small amounts of radiation which are expected to accumulate from radioactive fallout may also be effective in producing leukemia. It should be noted here that there are two routes by which fallout may exert its effects. Mixed fallout products outside the body emit long-range or gamma radiation which then can cause whole-body irradiation. Fallout products also emit short-range radiation which will be effective as far as leukemia is concerned when the fallout products are ingested into the body. Here, radiostrontium is especially important since it accumulates near the bone marrow where certain types of leukemia are thought to originate.

Recently there have been suggestions that the public would not suffer any appreciable effects if the body level of strontium 90 were to reach 100 sunshine units of this element—this is an amount which is one-tenth that permitted workers with radioactive materials. Now, if the direct proportionality law continues to hold at even the lowest dose levels—and there is little reason to believe it will not hold—then it becomes possible to calculate the number of cases of leukemia

that will arise if, for example, the present population of the United States were to be constantly exposed to 100 sunshine units of strontium 90. The prediction calculated in this way is that 500 to 1,000 cases of leukemia would occur annually from this source alone. The direct proportionality law further predicts that constant exposure to even one sunshine unit of strontium 90 would be capable of producing about 5 to 10 cases of leukemia annually in the United States population.

[Reprinted from Science, May 17, 1957]

LEUKEMIA AND IONIZING RADIATION [1]

(By E. B. Lewis)

Quantitative estimates of the genetic effects of ionizing radiation on human beings have been carried out by a number of investigators (1-3). Estimates of this kind involve extrapolating from induced mutation rates in such organisms as *Drosophila* and mice. Quantitative estimates of the somatic, or direct, effects of radiation must also be attempted if the biological hazards of ionizing radiation are to be fully assessed. In the case of direct effects, it is particularly difficult to extrapolate from results with lower organisms, and it becomes important to have data on man himself.

It is the purpose of this article to examine the evidence for the induction of leukemia in man by ionizing radiation. Although ionizing radiation has been implicated in the production of other human malignancies, such as bone tumors (4) and thyroid carcinoma (5, 6), only the data on induction of leukemia seem sufficiently extensive to warrant a study at this time of the quantitative relationship between incidence of the disease and dose of radiation. Evidence bearing on this relationship is drawn from studies of leukemia among four groups of individuals: (i) Survivors of atomic bomb radiation in Japan; (ii) patients irradiated for ankylosing spondylitis; (iii) children irradiated as infants for thymic enlargement; and (iv) radiologists. An estimate of the probability of developing leukemia per unit dose of radiation (7) per time unit is derived for each of these groups. This probability of radiation-induced leukemia is discussed and its application to a specific example of a possible radiation hazard—namely radiostrontium—is outlined. Certain properties of the disease, relevant to the radiation studies, are presented first.

DESCRIPTION OF THE DISEASE

Leukemia is a malignant disease in which the leucocytes undergo a more or less unrestricted proliferation. The "acute" form of leukemia differs from the "chronic" form, not only in being usually of shorter duration, but also in being a more severe disease with a higher percentage of immature white blood cells in the circulating blood. Another classification of the leukemias is based on the type of white blood cell predominating in the marrow or in the circulating blood. The two most common of these types are known as granulocytic (or myelogenous) and lymphocytic (or lymphatic). The presumption is that the granulocytic type arises in the red bone marrow. The lymphocytic type is thought to arise in the lymphatic elements of the blood-forming system (thymus, spleen, and other lymph glands), although the marrow is not excluded as a source for this type.

SPONTANEOUS INCIDENCE OF LEUKEMIA

In 1947 Sacks and Seeman (8) reported that the recorded death rate from leukemia had increased steadily from 1900 to 1944 and at an accelerated rate after 1930. The death rate has continued to increase (9). By 1954 the crude mortality rate for leukemia among the United States white population had reached 68 per million individuals per year (10) compared with 42 per million in 1940 (11). The male and female crude death rates in that population were 79 and 58 per million per year, respectively, in 1954 (10). The observed increase in death rate from this disease may be partly due to improvements in diagnosis. Other factors may also be responsible, such as the increased exposure of the population to ionizing radiations employed in medicine and dentistry, as was recently discussed by Dameshek and Gunz (12).

[1] Dr. Lewis is professor of biology at the California Institute of Technology, Pasadena.

MacMahon and Clark (13) have recently studied the spontaneous incidence of the common forms of leukemia. They have attempted to determine the total number of valid cases diagnosed among residents of the borough of Brooklyn from 1943 to 1952, inclusive. In this study the over-all ratio of acute to chronic forms among the white population was nearly 1/1 (726/732), but there were marked differences in the incidence of these two forms with respect to age at time of diagnosis, as is shown in table 1 (14). The ratio of granulocytic to lymphocytic types in the Brooklyn study was 1.6/1 (512/318).

LEUKEMIA IN HIROSHIMA AND NAGASAKI

Studies of the incidence of leukemia among survivors of the atomic bomb bursts over Hiroshima and Nagasaki have established that ionizing radiations induce leukemia in man (15–17). Table 2 summarizes the incidence of leukemia in terms of four concentric zones about the hypocenter (the point on the ground under the aerial burst). This table includes only those cases of leukemia which were (i) diagnosed during the period January 1948 to September 1955, inclusive; (ii) resident in the city at the time of diagnosis (Hiroshima) or at the time of death (Nagasaki); and (iii) considered by several criteria to be valid cases of the disease (18). For each zone, the estimate of the number of exposed survivors resident in Hiroshima as of October 1950 (17) has been combined with the corresponding number for Nagasaki (15) to obtain a combined population estimate for both cities.

Lange et al. (16) have studied the pattern of types of leukemia in the exposed and unexposed populations of Hiroshima and Nagasaki. They conclude that radiation induces the same pathological types that are found spontaneously and, as far as can be judged by the limited data, induces them in roughly the same relative proportions that occur spontaneously. This is especially evident in the case of chronic lymphocytic leukemia, which is rare in both the exposed and unexposed Japanese populations, whereas it is the most common form of leukemia after age 50 in the United States (13). Lange et al. found no marked influence of sex or age on the incidence of leukemia among the exposed populations. However, they point out that, for a number of reasons, the data are not very satisfactory for assessing the incidence in individuals under 5 years of age (19).

TABLE 1.—*The spontaneous incidence of leukemia for the white population of Brooklyn, N. Y., 1943–52, according to chronicity—Data of MacMahon and Clark (13)*

Age	Percentage in age interval	Incidence per million per year [1]		
		Acute	Chronic	Total
0 to 9	15.3	48	1	49
10 to 19	13.5	24	2	26
20 to 29	16.5	12	6	18
30 to 39	16.5	20	14	34
40 to 49	14.8	22	28	50
50 to 59	11.8	44	64	108
60 to 69	7.6	58	133	191
70 and over	3.9	59	182	241

[1] The incidence of subacute and unknown types of leukemia have been allocated to the observed incidences for the acute and chronic forms in the proportions in which the latter were diagnosed at each age interval (14).

The published accounts of leukemia in Hiroshima and Nagasaki have not contained estimates of the doses received by the bomb survivors. Recently, however, distance-dose curves for these cities have been published (20). These curves give, for each city, the relationship between the slant distance from the burst and the "air" (unshielded) dose of gamma rays and of neutrons. From this information, curves have been constructed (fig. 1) showing the relation between distance from the hypocenter and the combined "air" dose from gamma rays and neutrons (fig. 1) in rem (7). In computing the latter dose, it has been assumed that

the relative biological effectiveness (RBE) of neutrons for inducing human leukemia is 1.7. This value is chosen since Dunning has recently stated that "for generalized whole-body effectiveness it is thought that 1.7 is a reasonable representative value for neutrons from a nuclear detonation" (21). This is believed to be a conservative estimate for the RBE, since Upton et al. (22) found that the RBE for induction of leukemia in mice by fast neutrons is somewhat lower than this.

In the absence of precise knowledge of the distribution of survivors within the different zones about the hypocenter, it is conservative to take the mean "air" dose for a zone as the average "air" dose received by survivors in that zone. The zone from 0 to 999 meters, which is designated here as zone A, is a special case, however, since there was heavy mortality near its center. The mean dose for this zone has been computed for the portion of this zone extending from 850 to 999 meters. The majority of leukemia cases in zone A occurred in this latter region (15); moreover, 2 (among 5) cases at a distance closer than 850 meters had the type of shielding specified, and in each case it was listed as heavy (18). Since the doses for the two cities are slightly different at a given distance from the hypocenter, the average value of these two doses is used without correcting for differences in population size. In this way, a dose of about 1300 rem is arrived at for zone A. For zones B (100 to 1,499 meters) and 3 (1,500 to 1,999 meters), the mean doses are approximately 500 rem and 50 rem, respectively. At 2,000 meters the dose has fallen to 14 rem and by 2,500 meters to less than 5 rem. Since the majority of the population in zone D (from 200 meters on) was beyond 2,500 meters, the average dose is under 5 rem and is thus so low that zone D can be treated as if it were a "control" zone.

The relation of dose, estimated as described in the preceding paragraph, to the incidence of leukemia per year, based on the combined Hiroshima and Nagasaki data, is shown in table 3. The incidence per year in the "control" zone, D, is subtracted from the incidence in each of the other zones to obtain the "incidence of induced leukemia per year" in these zones. The values of the incidence of induced leukemia are likely to be minimum ones, since, as Lange et al. have noted, "some cases of leukemia have undoubtedly been missed and other cases have been omitted because of lack of adequate material to confirm the diagnosis" (16). The incidences of induced leukemia in zones A, B, and C have been divided by the respective means "air" doses in rem, derived in the preceding paragraph, to give estimates for the probability of induced leukemia for these zones. The values for this probability are seen to range from 0.7×10^{-6} to 0.9×10^{-6} per individual per rem per year. These are minimum estimates of the probability of induced leukemia, since the survivors were shielded in varying degrees from the "air" doses, calculated in the preceding paragraph. The shielding of survivors has two major components: (i) the body's own shielding of its blood-forming tissues by the surrounding bone and soft tissues; and (ii) external shielding by buildings or other shelters. A shielding factor of 2 is believed to be a conservative one for correcting for both of these components—the true factor might be at least 4 (23). The "best" estimate for the probability of induced leukemia from these data is, therefore, taken as approximately twice the aforementioned minimum estimates of 2×10^{-6} per individual per rem per year (of the 7.75-year period). A rought range for this probability is 0.7×10^{-6} to 4×10^{-6}.

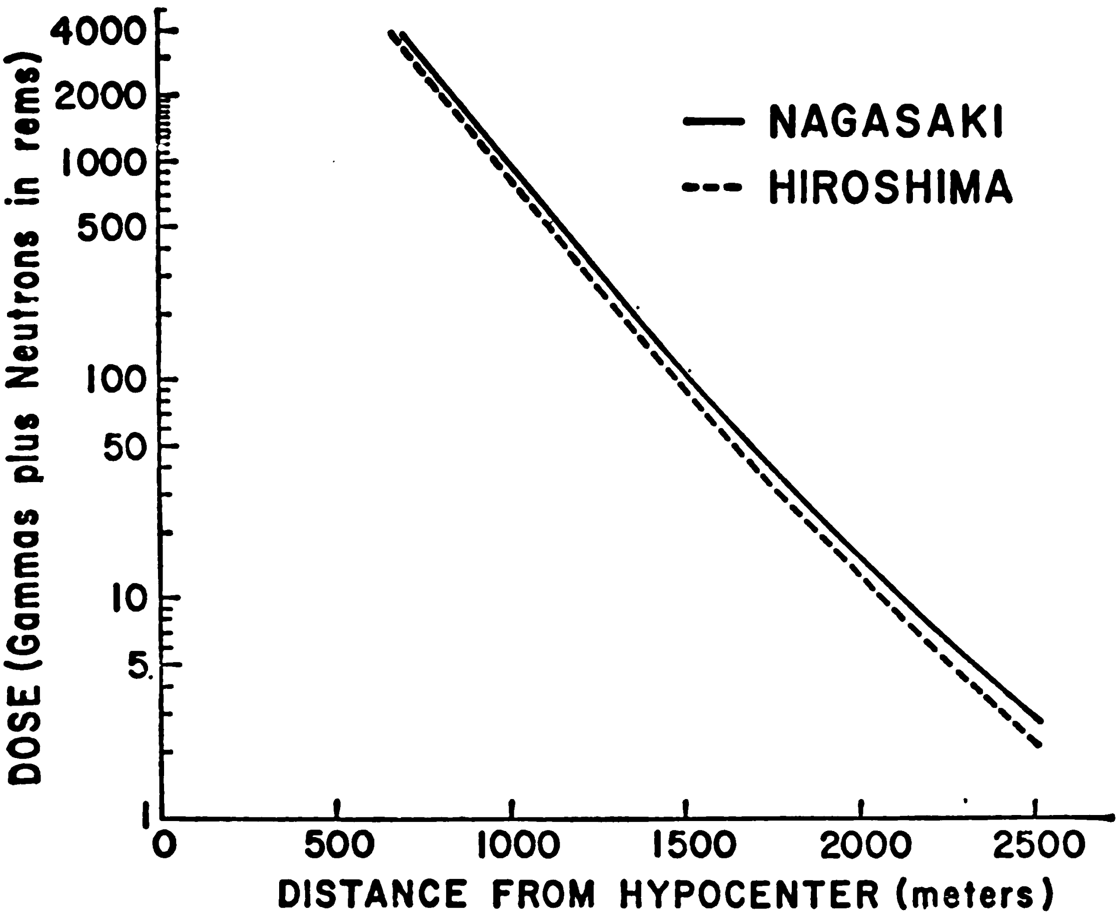


FIGURE 1. Distance-dose curves for atomic bomb blasts at Nagasaki and Hiroshima.

LEUKEMIA AND ANKYLOSING SPONDYLITIS

Court Brown and Doll (24) and others (25, 26) have investigated the incidence of leukemia among patients treated with X-rays for ankylosing spondylitis—a hereditary disease of the spine. Among 11,287 male patients irradiated during the period from 1935 to 1954, inclusive, 37 cases of leukemia were discovered. The average period of followup of these patients was "just under 5 years" (24). The distribution of cases by amount of treatment, measured as maximum dose in roentgens (7) to the spinal marrow, is shown in table 4. A highly significant increase in the incidence of leukemia is apparent among those receiving the heavier treatments.

Court Brown and Doll have estimated the expected incidence of leukemia in a comparable group of unirradiated normal males as 50 cases per million individuals per year. Subtraction of this expected incidence from the observed incidence of leukemia per year in the irradiated patients gives an estimate of the incidence of radiation-induced leukemia per year. This calculation has been carried out for each of the groupings of leukemia cases according to amount of treatment. For each such grouping between 500 and 2,750 roentgens, an average maximum dose to the spinal marrow is taken as the midpoint of the dose range (for example, for leukemia cases developing after treatments ranging from 500 to 999 roentgens, 750 roentgens is taken as the average dose). By dividing the calculated incidence of radiation-induced leukemia for each of the four groupings of this kind (col. 5, table 4) by the respective average maximum dose (col. 2, table 4), a set of four minimum estimates of the probability of leukemia per individual per roentgen (to the spinal marrow) per year is obtained. These latter estimates are seen to range from 0.3×10^{-6} to 0.6×10^{-6} per individual per roentgen per year (col. 6 of table 4). It seems likely that the absorbed dose to the entire red-marrow system would be lower than the stated doses to the spinal marrow by a factor of at least 2 or 3. Therefore, it is estimated that the probability of leukemia ranges from about 0.6×10^{-6} to 2×10^{-6} per individual per rad (to the red-marrow system) per year.

TABLE 2.—*Incidence of leukemia among the combined exposed populations of Hiroshima and Nagasaki by distance from the hypocenter (January 1948–September 1955)*

Zone	Distance from hypocenter (m)	Estimated population of exposed survivors (October 1950)	Number of confirmed cases of leukemia	Percentage of leukemia
A	0 to 999	1,870	18	0.96
B	1,000 to 1,499	13,730	41	.30
C	1,500 to 1,999	23,060	10	.043
D	2,000 and over	156,400	26	.017

TABLE 3.—*Incidence of leukemia per year among the combined exposed populations of Hiroshima and Nagasaki (January 1948 to September 1955) in relation to dose of radiation (gammas plus neutrons)*

Zone	Average maximum dose (rem)	Incidence of leukemia per million per year	Incidence of radiation-induced leukemia per million per year	Probability of leukemia per individual per rem per year
A	1,300	1,200	1,179	0.9×10^{-6}
B	500	390	369	$.7\times10^{-6}$
C	50	56	35	$.7\times10^{-6}$
D	5	21		

LEUKEMIA AND THYMIC ENLARGEMENT

Simpson et al. (6) have traced a series of 1,400 individuals who had irradiated as infants for an enlarged thymus condition. The average period of followup appears to have been about 15 years. As a "control" 1,795 unirradiated siblings were also traced. In the irradiated group there were 7 confirmed cases of leukemia (and 1 unconfirmed case), while there was none in the control group. The calculated number of cases of leukemia that would have been expected in a sample of comparable size and age from the general population was 0.6. The difference between this expectation and the observed number of cases (seven) is statistically significant (*P* less than 0.01).

In the majority of the 1,400 infants, the radiation (X-rays) had been more or less restricted to the chest region. It was estimated that the air dose to the thymus region was more than 200 roentgens ("the great majority being less than 600 r") in 57 percent of the treated individuals and under 200 roentgens in the remainder. The average absorbed dose to the entire lymphatic system is roughly estimated as 100 to 300 rad. On the basis of these dose estimates, the probability of leukemia ranges from 1×10^{-6} ($6.4/15\times1{,}400\times300$) to 3×10^{-6} per rad (to the lymphatic system) per individual per year. The number of cases (seven) on which this estimate is based is, of course, small. The 95-percent confidence interval for an observation of 7 when the frequency is as low as in the present case lies between 3.3 and 13.2 (27). Therefore, the probability of leukemia in the thymic enlargement group may well range from 0.4×10^{-6} to 6×10^{-6} per rad (to the lymphatic system) per individual per year.

LEUKEMIA AMONG RADIOLOGISTS

March (28, 29) and others (30, 31) have called attention to the fact that among physicians the percentage of deaths from leukemia is much higher for radiologists than for physicians who are not radiologists. The percentage of deaths that are due to leukemia can be a misleading statistic, however, since it is sensitive to differences in age distribution between the groups of individuals being compared. Such differences are marked in the case of radiologists, on the one hand, and all physicians, on the other, as is discussed later. To assess the radiation factor in the leukemia among radiologists, it becomes necessary to

estimate (i) the death rate from leukemia among radiologists (the number of deaths per total number of living radiologists), and (ii) the expected death rate from leukemia among radiologists if they had received no occupational exposure to radiation.

TABLE 4.—*Incidence of leukemia among ankylosing spondylitis patients receiving different doses of radiation (X-rays)—Data from Court Brown and Doll (24)*

Maximum dose to spinal marrow (r.)	Estimated average maximum dose (r.)	Number of males developing leukemia	Crude incidence per million males per year	Incidence of radiation-induced leukemia per million males per year	Probability of leukemia per individual per r. (to spinal marrow) per year
0	----------	----------	50	----------	----------
Under 500	----------	2	220	170	----------
500-999	750	8	410	360	0.5×10^{-6}
1,000-1,499	1,250	8	420	370	0.3×10^{-6}
1,500-1,999	1,750	8	1,130	1,080	0.6×10^{-6}
2,000-2,749	2,375	6	1,300	1,250	0.5×10^{-6}
2,750 or more	----------	5	1,760	----------	----------

The study of motality among medical specialists by Dublin and Spiegelman (32) has been used here as a guide in computing the afore-mentioned rates and as source of data for the years 1938 to 1942, inclusive. The latter data and additional data for the years 1943 to 1952, inclusive, are summarized in table 5. The term radiologist is restricted here, following Dublin and Spiegelman, to those physicians who were listed in editions of the American Medical Directory (33) as limiting their practice to radiology (and roentgenology). Since only deaths occurring at ages 35 to 74 years, inclusive, were included in the mortality study for 1938–42, the same practice is adopted here for the supplementary 10-year period.

In order to estimate the mean annual population of radiologists at ages 35 to 74 years, during the entire 15-year period from 1938 to 1952, the age distribution of radiologists is required. This age distribution for the year 1940 was computed by Dublin and Spiegelman from the 1940 edition of the American Medical Directory and is shown in table 6. The age distribution for a similar group of radiologists in 1950, also shown in table 6, has been computed (34) by reference to the 1950 edition of this directory. The 1940 age distribution was based on a total of 1595 radiologists of whom 1451.5 (91.0 percent) can be inferred to have been at ages 35 to 74 years, inclusive (32). The 1950 age distribution was based on a total of 2443 radiologists of whom 2250 (92.1 percent) are calculated to have been at ages 35 to 74 years, inclusive, as of July 1, 1950. The mean number of radiologists (at ages 35 to 74) per year from 1938 to 1952, inclusive, is roughly approximated as 1850.7, which is the average of the number of such radiologists in 1940 and the corresponding number in 1950.

Deaths from leukemia occurring at ages 35 to 74 years, inclusive, among radiologists have been located in several ways with the results shown in table 5. For the period from 1938 to 1942, inclusive, five such deaths are recorded by Dublin and Spiegelman. For the period from 1943 to 1948, inclusive, the carefully documented studies of March (28, 29) record eight such deaths. For the remaining 4-year period from 1949 to 1952, inclusive, four additional deaths from leukemia have been located by reference to death notices in a medical journal (35). Thus, a minimum of 17 deaths from leukemia has been located among radiologists who died between the ages of 35 and 74 years during the 15-year period from 1938 to 1952. The upper and lower 95-percent confidence limits for this observation of 17 deaths are 25.5 and 10.8 deaths, respectively (27). Thus, a likely range of values for the average death rate from leukemia among radiologists at ages 35 to 74 years is 390 (10.8/15×1850.7) to 920 (25.5/15×1850.7) deaths per million per year, and the "best" estimate is 610 (17/15×1850.7) deaths per million per year (of the 1938-52 period).

TABLE 5.—*Deaths and death rates from leukemia among radiologists, at ages 35 to 74 years, by 5-year periods from 1938 to 1952, inclusive*

Period	Estimated number of radiologists at mid-point of period	Number of deaths from leukemia	Observed death rates per million per year	Expected death rates per million per year	Incidence of radiation-induced deaths per million per year
1938–42	1,451.5	5	690	101	589
1943–47	[1] (1,850.7)	6	550	[1] (121)	429
1948–52	2,250.0	6	530	141	389
(1938–52)	[1] (1,850.7)	17	610	[1] (121)	489

[1] The arithmetic average of the values for the 1938–42 and 1918–52 periods.

The expected death rate from leukemia among radiologists, if they had received no occupational exposure to radiation, is estimated by first calculating the death rate they would have experienced if subject to United States white male death rates from leukemia. This calculation has been made for a 3-year period from 1939 to 1941 by first computing (36) the mean annual age-specific United States white male death rates from leukemia (table 7) and then applying them to the 1940 age distribution of radiologists (table 6), restricting the computation to the 35- to 74-year age interval. The resultant expected death rate for the latter age interval is 63 deaths per million per year.

The same type of calculation has been carried out for a 3-year period from 1949 to 1951 by computing (36) the appropriate age-specific death rates for that period (table 7) and applying them to the 1950 age distribution of radiologists. The resultant expected death rate is 88 deaths per million per year.

The average of the rates for the 1939–41 and 1949–51 periods is 76 deaths per million per year. The latter rate should roughly approximate the mean annual death rate from leukemia which radiologists would have experienced during the 1938–52 period if they had been subject to United States white male death rates for this disease. The observed death rate for this period was 610 deaths per million per year (table 5), which is 8 times the expected rate, just calculated.

It is possible, however, that reasons other than radiation exposure may account for the high death rate from leukemia among radiologists. For example, leukemia might be more likely to be diagnosed among radiologists than among the group of all United States white males. To correct for such possibilities as this, the expected death rate of 76 deaths from leukemia per million per year, calculated in the preceding paragraph, is multiplied by a correction factor of 1.6. This factor is the ratio of the observed number of deaths from leukemia among physicians who were nonradiologists to the expected number of deaths calculated on the assumption that such physicians were subject to United States white male age-specific death rates for leukemia.

This factor of 1.6 has been inferred from data for the 1938–42 period given by Dublin and Spiegelman (32) and is applied throughout the entire 15-year period from 1938 to 1952 to give the expected death rates shown in table 5. It is a conservative factor in the sense that it is possible that the increased death rate from leukemia among physicians who are nonradiologists is partly due to exposure of some of them to ionizing radiation (31). Thus, 121 (1.6×75.5) deaths per million per year is probably a conservative estimate of the expected death rate from leukemia among radiologists in the 1938–52 period, if they had received no exposure to radiation.

The expected death rate from leukemia, just calculated, would be expected to yield 3.4 ($15 \times 1850.7 \times 121 \times 10^{-6}$) deaths among radiologists during the 1938–52 period. It is appropriate at this point to compare this with the observed number; namely, 17 deaths (table 5). The probability of observing 17 or more when the expected number is 3.4 is readily obtained from the Poisson distribution and is found to be less than 1×10^{-6}. Hence, the observed value exceeds the expected value at a statistically highly significant level.

The difference between the expected death rate from leukemia calculated on the assumption of no occupational exposure to radiation and the observed death rate is designated the "incidence of radiation-induced leukemia," L. For a stationary population chronically irradiated at a constant dose rate, D, the incidence, L, can be approximated if it is assumed that the probability of leukemia per rad of accumulated dose per year, P_L, is a constant for all age groups in the population and for all values of the accumualted dose. On these assumptions, a sta-

tionary population exposed for a mean number of years, E, to the dose rate, D, will have an incidence of radiation-induced leukemia that can be expressed as follows:

$$L(=)(D)\cdot(E)\cdot(P_L)$$

To estimate the value of E, it is assumed that occupational exposure of radiologists starts at age 25 and ends at age 65. The value of E for individuals who were at ages 35 to 74 in 1940 can then be approximated from the age distribution of radiologists for that year (table 6) and is found to be 24.7 years. The corresponding value of E approximated from the 1950 distribution (table 6) is 24.1 years. The average of these 2 values, 24.4 years, is used as the value of E for the population of radiologists who were at ages 35 to 74 years in the 1938–52 period. The best estimate of L is 489 deaths per million per year (table 5), and a likely range of values for L is 270 to 800 deaths per million per year, based on the 95-percent confidence limits for the observed death rate of 610 deaths per million per year. For reasons discussed later, the value of D is estimated to lie between 3 and 30 rad per year.

The best estimate for the range of values of P_L is then given by the expression

$$P_L \text{ (likely range)} = \frac{489}{24.4\times(3 \text{ to } 30)} = (0.7 \text{ to } 7)\times10^{-6}$$
per individual per rad per year

A broader range, based on the confidence limits for L, is $(0.4 \text{ to } 11)\times10^{-6}$ per individual per rad per year.

TABLE 6.—*Age distribution of radiologists in 1940 (32) and 1950*

Age	Percentage distribution as of	
	1940	1950 (July 1)
Under 35	8.3	6.1
35 to 44	31.3	38.9
45 to 54	33.8	26.6
55 to 64	19.8	18.7
65 to 74	6.1	7.9
75 and over	0.7	1.8
Total	100.0	100.0

Since the dose rate, D, in the foregoing discussion, represents the average absorbed dose rate to the leucocyte-producing system, it is likely to be lower by at least a factor of 2 than the "air" dose rate to which radiologists were exposed. The recommended maximum dose rate (in air) for such workers was set at 0.2 roentgen per day in 1931 by the United States National Committee on Radiological Protection; this rate was reduced to 0.1 roentgen per day in 1936 and to 0.05 roentgen per day in 1949. Although some radiologists may well have exceeded the recommended dose rates, it seems unlikely that the average dose rate for all radiologists in the group under consideration would have exceeded the permissible limits set in 1931. Thus 30 rad per year has been taken as an upper limit for the absorbed dose to the leucocyte-producing system. The lower limit for D has arbitrarily been taken as one-tenth of this, or 3 rad per year.

This estimate that D might be much less than 30 rad per year is somewhat at variance with the following conclusions from a recent study of longevity among radiologists (37). "In comparison with nonexposed physicians, the shortening of life of radiologists is 5.2 years, or 11 percent of the adult life span (after 20 years). If extrapolation from the animal data * * * is permissible, this would be expected to result from chromic whole-body exposure to about 1.5 LD_{50} dose, or possibly 1,000 roentgens. Although this exposure was partial body and possibly less effective, it seems unlikely that the equivalent whole-body exposures differed from the above value by a factor greater than 2 or 3. Consequently, it appears that, within these limits at least, extrapolation from short-lived animals to man may be made with some confidence on the basis of percent life shortening per unit dose."

The shortening of life by 5.2 years just cited is based on the observation that during the period 1930–54 the difference between the mean age at death of physicians estimated to have had "no known contact with radiation" and the mean

age at death of radiologists was 5.2 years (37). It can be calculated (38), however, that a difference of at least 6 years would be expected in this case solely as the result of differences in age distribution (as of 1940 or 1950) between radiologists, on the one hand, and all physicians, on the other. That is, radiologists may have a slightly longer life span than physicians as a whole. Moreover, for the 1938–42 period, Dublin and Spiegelman showed that, after appropriate adjustment for differences in age distribution, the total death rate from all causes was lower for radiologists than it was for all physicians combined; however, this rate was slightly higher for radiologists than it was for all specialists combined. Thus, either a chronic whole-body exposure of 1,000 roentgens does not have a marked effect on longevity or, more probably, radiologists have averaged much less than this as a lifetime absorbed dose.

TABLE 7.—*United States white male death rates from leukemia per million per year*

Age	Period	
	1939–41	1949–51
25 to 34	18	26
35 to 44	29	34
45 to 54	55	68
55 to 64	104	149
65 to 74	154	276
75 plus	181	385

Discussion

Table 8 summarizes the various estimates of the probability of leukemia derived from the four sets of data reviewed here. For acute whole-body irradiation the best estimate of this probability will be taken as 2×10^{-6} per individual per rad per year. This value is based on the studies of leukemia among the survivors of atomic-bomb radiation. For acute partial-body irradiation, the available data are conveniently discussed in terms of a probability of leukemia "of bone-marrow origin" (ankylosing spondylitis patients) or a probability of leukemia of "lymphatic origin" (thymic-enlargement patients).

As has already been noted, granulocytic and lymphocytic leukemias may have bone-marrow and lymphatic origins, respectively. Since these two types of leukemia constitute the majority of all leukemias and occur in proportions which are, for present purposes, roughly equal, it is assumed that the best estimate of the probability of leukemia of bone-marrow origin is one-half of that for all leukemia, or 1×10^{-6} per individual per rad to the red marrow per year. Similarly, the best estimate of the probability of leukemia of lymphatic origin is taken as 1×10^{-6} per individual per rad to the lymphatic system per year.

These estimates fall within the range of values calculated for either the ankylosing spondylitis patients or the thymic-enlargement patients. Moreover, there is some evidence that leukemia following irradiation of the spinal marrow is primarily granulocytic (26). Whether lymphocytic leukemia predominates in the thymic-enlargement series (6) is uncertain on two grounds: (i) It is difficult to differentiate granulocytic and lymphocytic types in infants and children; and (ii) some irradiation of bone marrow would, in any case, be expected in this series of patients (39). Finally, the best estimate of the probability of leukemia following chronic whole-body irradiation is taken as identical with that for acute whole-body irradiation—namely, 2×10^{-6} per individual per rad (of accumulated dose) per year. This value is seen to be close to the lower limit of the range of values deduced for radiologists.

Simpson et al. (6) and Court Brown and Doll (24) point out that their studies lack a control in the form of an unirradiated series of patients. Thus, the possibility is not excluded that thymic-enlargement and ankylosing spondylitis predispose toward leukemia. However, a comparison of the various estimated ranges for the probability of leukemia (table 8) suggests that patients with the aforementioned conditions are no more prone to develope leukemia than are radiologists or the Japanese survivors.

Presently available determinations of the incidence of induced leukemia per year are based on average followup periods that are comparatively short in

terms of the normal human life span. Thus, the probability of leukemia per individual per rad per year may not be constant for an indefinite period beyond the initial time of irradiation. By choosing the lower limit for the probability of leukemia at about 0.7×10^{-6} per individual per rad per year, it is felt that adequate account is taken of the possibility that the incidence of leukemia per year following an acute dose of radiation may, as some have sugegsted on the basis of the data from Hiroshima (37), reach a peak followed by a steady decline. It is noteworthy, however, that Court Brown and Doll have concluded, from an analysis of 108 cases of leukemia among the exposed populations of Hiroshima and Nagasaki, that "the data provide no evidence of a sharp peak in incidence at any particular period after the explosion nor any clear indication that the incidence had yet begun to diminish by the end of the ninth year" (40).

The probability of leukemia per individual per rad per year is nearly constant over a rather wide range of doses in the case of the Japanese survivors (table 3) and in the case of ankylosing spondylitis patients (table 4). This is presumptive evidence that the relationship between incidence of induced leukemia and dose of radiation is either linear or approximately linear. A striking feature of the Japanese data shown in table 2 is that the incidence of leukemia in zone C—the zone with a calculated average "air" dose of 50 rem—is significantly higher than in zone D, the control zone ($P=0.02$, by the Chi-square test). Thus, these data provide no evidence for a threshold dose for the induction of leukemia. Moreover, chronic irradiation at a relatively low dose rate (perhaps 0.1 rad per day or less) appears to induce leukemia in radiologists at a rate per rad which is comparable to that observed for the Japanese survivors. This finding also fails to support the concept of a threshold dose below which leukemia will not develop.

A linear relationship between the incidence of leukemia and dose of radiation, which is suggested by the available data for man, may have its explanation in a somatic mutation hypothesis (41). Thus, radiation-induced leukemia may result from a somatic gene mutation, presumably occurring in one of the precursor cells destined to give rise to mature leucocytes. Such a mutation might cause the cell, or its descendants, to acquire an unregulated growth habit, or to release, or to respond to, viruslike or hormonal agents—to mention only a few of many possibilities. Thus, the somatic mutation hypothesis and other hypotheses for the origin of radiation-induced malignancies (42) are by no means mutually exclusive. Gene mutation has long been known to show a linear relationship with respect to dose of ionizing radiation from studies with *Drosophila*. This linearity has been extended by Spencer and Stern (43) to doses of 50 and 25 roentgens. Gene mutation is also known to be directly proportional to the accumulated dose of radiation, even when the radiation is chronically administered at a relatively low dose rate, as in the studies of Uphoff and Stern (44).

The concept of somatic mutation is also helpful in attempting to explain the long period of time which sometimes intervenes between irradiation and onset of leukemia. Thus, it may be that some of the precursor cells of leucocytes lie quiescent for years before they are brought into leucocyte production. A somatic mutation in such a cell might, therefore, be long delayed in producing its effect.

In leukemia of spontaneous origin, there is also likely to be a somatic mutation component which would be attributable to spontaneous mutation in the somatic cells. In addition, there is likely to be a hereditary component in spontaneous leukemia—that is the presence of defective genes (dominant or recessive) which are transmitted through the germ line and which result in, or predispose toward the development of, leukemia. It is well known from the work of MacDowell and associates (45) that the pronounced differences among certain strains of mice in suspectibility to leukemia have a genetic basis. In man, there is evidence for familiar factors in leukemia from the work of Videbaek (46) and others, but the type of inheritance involved is not clear (47). It should be noted that cases of leukemia which arise somatically—for example, those which are radiation induced—will tend to obscure the analysis of the hereditary component in leukemia (48).

It is likely that there will be individual differences in susceptibility to radiation-induced leukemia as well as to spontaneous leukemia. The indication of a linear relationship between dose of radiation and incidence of leukemia implies that there are some individuals in whom a single radiation-induced event (per-

haps a gene mutation) suffices to produce leukemia. There may, however, be other individuals in whom two or more such events would be required before leukemia would be manifested. Thus, the values of the probability of leukemia per individual per rad per year that have been derived here apply to the average individual in a given population, but do not necessarily apply equally to each and every individual in that population.

SPONTANEOUS LEUKEMIA AND NATURAL BACKGROUND RADIATION

The possibility that a portion of the spontaneous incidence of leukemia may be due to radiation from natural background sources is briefly considered. For this purpose, the same type of approximation procedures employed for assessing radiation-induced leukemia among radiologists is applied to the data of MacMahon and Clark on the spontaneous incidence of leukemia in the white population in the borough of Brooklyn (table 1). Thus, the incidence of leukemia, L_B, that would be attributable to irradiation of that population from natural background sources can be approximated by assuming that it is a product of the following three quantities: (i) A constant dose rate, D_n, from all natural background sources; (ii) the mean age, E_B, of the Brooklyn population, which is equivalent to the mean number of years exposed to D_n; and (ii) the probability of leukemia, P_L per individual per rad per year. The value of D_n is not known but probably is in the range of 0.1 to 0.2 rad per year (49). The value of E_B can be readily approximated from the age distribution (table 1) of the Brooklyn population, and is about 33.7 years. The value of P_L is chosen as the best estimate from the aforedescribed radiation studies, namely 2×10^{-6} per individual per rad per year. Thus, L_B can be estimated as 7 to 13 cases per million per year. The observed total spontaneous incidence in this study was 64.4 cases per million per year (13). Thus, possibly 10 to 20 percent of the spontaneous incidence of leukemia in this Brooklyn population is attributable to ionizing radiation from natural background sources.

A maximum value for the probability of radiation-induced leukemia may also be inferred from the Brooklyn data. The calculation of such a value is based on the incidence of acute leukemia, since in this form of the disease the time of onset and time of diagnosis probably nearly coincide, while in chronic leukemia some years may elapse between these two times. The observed incidence of acute leukemia has a minimum value of 12 per million per year which occurs in the 20–29 age group (table 1). By assuming that individuals in that age group had an average accumulated dose of not less than 2.5 rad (0.1 rad per year for 25 years) and by further assuming, as an artifice, that all of the acute leukemia in that age group was due to radiation, the probability of acute leukemia may be estimated to have an upper limit of 5×10^{-6} ($12\times10^{-6}/2.5$) per individual per rad per year. Since the overall ratio of acute to chronic forms was about 1/1 in the Brooklyn data, it may be inferred that the maximum value, or upper limit (table 8), of the probability of leukemia (acute and chronic) is about 10×10^{-6} per individual per rad per year.

APPLICATION TO RADIOSTRONTIUM EXPOSURE

The foregoing estimates of the probability of radiation-induced leukemia have been attempted in order to have some basis for assessing direct effects of ionizing radiations on human populations. An example of the application of these estimates to a manmade radiation exposure—namely, that from radiostrontium (Sr-89 and Sr-90)—is briefly discussed (50).

The maximum permissible concentration (MPC) of Sr-90 has been set at 1 microcurie for the total body for workers with radioisotopes (51). A level of 1 microcurie of Sr-90 per 1,000 grams of calcium (the mass of calcium in the average adult individual) has been designated as 1 "MPC" unit of Sr-90 (52). Various estimates are at hand for the level of radiostrontium that is being accumulated in the human body as the result of past testing of atomic weapons (53). The present discussion is restricted to examination of the following recent suggestion for a permissible level (presumably of Sr-90) for the population at large (54). "There seems no reason to hesitate to allow a universal human strontium (very similar chemically to calcium) burden of one-tenth of the permissible, yielding 20 rep in a lifetime, since this dose falls close to the range

of values for natural radiation background. Visible changes in the skeleton have been reported only after hundreds of reps were accumulated and tumors only after 1,500 or more."

A body level of 0.1 MPC is expected to irradiate skeletal tissue at a dose rate of about 0.25 rad per year, on the assumption of uniform distribution of Sr–90 throughout that tissue. Because of the limited range in tissue of the beta particles emitted in the decay of Sr–90 and of its daughter element, Y–90, the leucocyte-producing cells may receive somewhat less than this dose rate, depending on the exact location of such cells with respect to the surrounding calcium of the bone. This reduction factor of perhaps 2, tends to be offset by the fact that ingested Sr–90 is not uniformly distributed throughout the skeletal tissue, but appears instead to be concentrated in regions more actively concerned with red-marrow formation (55). The dose rate to the leucocyte-producing cells is estimated as 0.1 to 0.2 rad per year for a body level of 0.1 MPC of Sr–90. This irradiation will be largely restricted to the skeletal tissue, since (i) the radiation from the decay of Sr–90 is exclusively of the beta type and (ii) 70 percent of the Sr–90 in the body is estimated to lie in the skeletal tissue (51). Hence, leukemia induced by Sr–90 would be expected to be largely of bone-marrow origin (56).

TABLE 8.—*Summary of the estimates of the probability of radiation-induced leukemia per individual per rad per year*

Source of estimate	Type of radiation	Region irradiated	Types of leukemia produced	Probability of leukemia of specified type per individual per rad (or rem) to region irradiated per year: Estimated range, Lower limit	Estimated range, Upper limit	Best estimate
Atom-bomb survivors	Gamma rays plus neutrons	Whole body	All	0.7×10^{-6}	3×10^{-6}	2×10^{-6}
Ankylosing spondylitis patients	X-rays	Spine	Granulocytic (only?)	0.6×10^{-6}	2×10^{-6}	1×10^{-6}
Thymic enlargement patients	do	Chest	Lymphocytic (only?)	0.1×10^{-6}	6×10^{-6}	1×10^{-6}
Radiologist	X-rays, radium, etc	Partial to whole body	All (?)	0.1×10^{-6}	11×10^{-6}	2×10^{-6}
Spontaneous incidence of leukemia (Brooklyn, N. Y.).	All natural background sources	Whole body	do		10×10^{-6}	2×10^{-6}

The problem of assessing the incidence of Sr–90-induced leukemia from a constantly maintained level of Sr–90 is essentially identical with that dealt with here for determining the component of the spontaneous incidence of leukemia owing to natural background radiation. Thus, the incidence of Sr–90-induced leukemia in a stationary population maintaining a constant level of 0.1 MPC of Sr–90 is considered to be the product of (i) a dose rate of 0.1 to 0.2 rad per year to red bone marrow; (ii) a mean age for the stationary population of 31.7 years, which is that expected from the age distribution of the total United States white population as of July 1, 1955 (57); and (iii) a probability of leukemia of bone marrow origin of 1×10^{-6} per individual per rad to bone marrow per year. This computation gives an incidence of 3 to 6 cases of Sr–90-induced leukemia per million per year. For a population of 1.6×10^{8} individuals, the current population of the United States, the expected number of cases of leukemia induced by a constantly maintained level of 0.1 MPC of Sr–90 would thus be about 500 to 1,000 per year. The range for this estimate is a factor of about 3, giving 150 to 3,000 cases per year. Currently (1954), there are about 10,500 deaths from leukemia per year in the United States population (10). Thus, if Sr–90 induces leukemia of bone-marrow origin at the same rate (per rad as X-rays and radiations from atomic bombs, then a constantly maintained level of 0.1 MPC of Sr–90 would be expected to increase the present incidence of leukemia (in the United States) by about 5 to 10 percent.

SUMMARY

Leukemia in man can be induced by ionizing radiations, and also occurs spontaneously. For the average individual in a population, the probability of developing radiation-induced leukemia is estimated to be 2×10^{-6} per rad (unit of absorbed dose of radiation) per year. The available data from 4 independent sources make it likely that this estimate is valid within a factor of about 3, giving a range from 0.7×10^{-6} to 6×10^{-6} per rad per year. It is pointed out that 10 to 20 percent of the spontaneous incidence of leukemia (Brooklyn, 1943–52) may result from radiation from natural background sources. It is estimated that a 5- to 10-percent increase in the current spontaneous incidence of leukemia would occur if the population were to reach and maintain a body level of Sr–90 amounting to one-tenth of the "maximum permissible concentration."

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34. The 1950 distribution is based only on radiologists listed in the section of the 1950 American Medical Directory devoted to membership in radiological societies. Each name in that list was looked up in the main body of the directory to determine year of birth and type of specialization. Only those listed as "R*" (an asterisk signifies that practice is limited to radiology) and resident in the continental U. S. were used in compiling the final age distribution. This procedure therefore fails to include radiologists who were nonmembers of radiological societies; however, this deficiency has been taken into account by establishing that the 12 deaths from leukemia from 1943–52, inclusive, were in fact radiologists whose names were listed in the section of the 1940 or 1950 directory devoted to membership in radiological societies. (I am indebted to Alethea Miller, Janet Chaitkin, and Joan Lewis for assistance in compiling the 1950 age distribution.)

35. The procedure was to obtain a list of deaths of members of one of the leading radiological societies and to search for the cause of death in the death notices of the Journal of the American Medical Association. In the period 1949–52, inclusive, only some 70 percent of all such deaths were found to have a cause of death listed. In order to have a conservative estimate of the incidence of leukemia, no correction for this defect is attempted. The four deaths from leukemia in the 1949–52 period have the following volume and page locations in the aforementioned journal: 144, 407; 147, 1065; 148, 218, 151, 488.

36. Death rates from leukemia for the years 1939–41 have been obtained from reference 11 and computed for the 1949–51 period from Vital Statistics of the United States (Federal Security Agency, Washington, D. C., 1949–51). Sources for the living population were Current Population Repts., Series P-25, No. 98 (1954); No. 114 (1955); No. 121 (1955). (U. S. Bur. of the Census, Washington, D. C.)

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Representative HOLIFIELD. We are going to have as our next witness Dr. Shields Warren from the Deaconess Hospital in Boston, and he is going to read, as I understand it, a statement from Dr. Jacob Furth on the subject of leukemia.

Dr. Warren, it is a great privilege to have you with us, and we would like to hear from you now.

STATEMENT OF DR. SHIELDS WARREN, NEW ENGLAND DEACONESS HOSPITAL, BOSTON, MASS.[1]

Dr. WARREN. I appreciate this opportunity very very much. I have been impressed that during these useful and well-planned hearings a number of scientists who are interested in radiation are presenting their findings and views. As one who has worked on the injurious effects of radiation since 1925, I am very happy to see the great influx of enthusiastic workers into this field.

I further appreciate the kindness of the committee in allowing me to testify, and I wish to say that I am speaking as an individual, and not for the various groups of which I happen to be a member.

[1] New England Deaconess Hospital, 195 Pilgrim Rd., Boston 5, Mass. Pathology. Cambridge, Mass., Feb. 26, 1898; m. 23; c. 2. A. B., Boston, 18, hon. S. D., 49; M. D., Harvard, 23; hon. D. Sc., Western Reserve, 52; hon. LL. D., Tulane, 53. Asst. path., Boston City Hosp., 23–25; instr. Path., Harvard Med. Sch., 25–36, asst. prof., 36–48, Prof., 48–; Pathologist, New Eng. Deaconess Hosp., 2 27–; New Eng. Baptist Hosp., 28–; Huntington Mem. Hosp., 38–42; Pondville State Hosp., 28–; consulting pathologist, House of the Good Samaritan, 27–43; Channing Home, 35–; dir. State Tumor Diagnosis Serv., Mass., 28–; Trustee, Boston Univ. Chmn. atomic casualty cmn., mem. exec. cmt., & cmt. path. Nat. Research Council; mem. Nat. Advisory Cancer Council, 46–49; dir. div. biol. & med., Atomic Energy Cmn., 47–52, mem. advisory cmt., 52–. Proctor award, Sci. Research Soc. Am., 52; Banting medal, Am. Diabetes Asn., 53. Diplomate, Am. Bd. Path. Med. C., U. S. N., 42-45. A. A. (v. Pres., 48); Assn. Path. & Bact. (v. pres., 47; pres., 48); Asn. Cancer Research (v. pres., 41; pres., 42–46); Soc. Exp. Path. (secy.-treas., 34–37; v. pres., 39; pres., 40; Soc. Exp. Biol.; Soc. Clin. Path.; Am. Acad.; Col. Path.; Am. Med. Asn.; Soc. Med. Consultanta W. W. II; Radiation Research Soc.; Gastroenterol. Asn.; Asn. Mil. Surg.; New Eng. Cancer Soc.; cor. mem. Asn. Path. Eng.; hon. mem. Peruvian Acad. Surg.; hon. mem. Mexican Asn. Path.; hon. mem. Indian Asn. Path. (From American Men of Science, 1955.)

Representative COLE. Mr. Chairman, I wonder if Dr. Warren would mind indicating the identity of these groups and committees of which he is a member, for the record, since it does not appear in his biography.

Dr. WARREN. Yes. I am the representative of the United States to the U. N. Scientific Committee on the Effects of Atomic Radiation. I am the Chairman of the Committee on Pathological Effects, of the National Academy of Sciences Radiation Group. I am also a member of the Committee on Genetics of the National Academy of Sciences. I am a member of the Advisory Committee on Biology and Medicine of the Atomic Energy Commission. Then there are various scientific associations with which I am also associated.

STATEMENT OF DR. JACOB FURTH,[2] PRESIDENT OF THE AMERICAN ASSOCIATION FOR CANCER RESEARCH (PRESENTED BY DR. SHIELDS WARREN)

Dr. WARREN. I think it would be appropriate in view of the fact that we have been hearing a very pertinent discussion of leukemia, to introduce at this point Dr. Jacob Furth's statement. He is an associate of Dr. Sidney Farber and myself, one whom I consider as probably the world's greatest authority on the experimental induction of leukemia. He say as follows:

FACTS

Radiation causes cancer and leukemia and other body changes, but it is also the best means of identifying and controlling many of them. Induction of neoplasms—by that meaning both leukemias and tumors—by radiations is a remote possibility and occurs rarely, while the benefits are immediate and usual; hence, radiation became a tool of medicine no physician or informed patient would want to be without. Most, if not all, increased hazard from radiations resulted from its medical use, a calculated risk well taken; it is steadily diminishing with recognition and dissemination of knowledge as to where the hazards lie.

SPECULATIONS

The statements that there is no threshold injurious dose to somatic cells, and every irradiation, no matter how small will cause cancer and leukemia, as is stated by some geneticists, are mere speculation. This applies also to the statement that even background irradiation is leukemogenic. The available facts allow argumentation of both sides. In my opinion, the statements that background irradiations will induce leukemia are contrary to observations and the reverse is more likely.

Reasons to assume that a threshold exists:

(*a*) All reported experiments on leukemia induction by irradiation have pointed to the existence of a threshold and none suggested the lack of it.

Dr. WARREN. I might say in addition that Dr. Furth has had access to all of these figures which you have seen on the chart here, and this is one of the conclusions he has come to.

(*b*) The complex mammalian host is capable of compensating for subtle damage. It has been shown that partial body irradiation is not conducive to leukemia development; the unexposed parts powerfully protect the exposed part. Thus, if direct hits cause mutation, humoral substances either counteract or reverse

[2] Began experimental studies of leukemia in 1928; was first or second (if so in independent work) to publish induction of leukemia, ovarian, breast, lung, and pituitary tumors in mice by ionizing radiation. Presented experimental evidence that leukemia is allied to cancer and some leukemias are related to mutations. Has numerous publications 1930–57 on the subject, all essentially confirmed. Presently, is president of the American Association for Cancer Research. Recipient of high awards and fellowships in scientific organizations in recognition of scientific contributions. (From American Men of Science.)

their actions. Were it otherwise, leukemia among physicians and radiologists and others exposed to small doses of X-rays repeated over long periods of time would be manyfold that actually observed. Some radiologists receive thousands and tens of thousands of roentgens while the population at large receives a few r. of background irradiation in a lifetime. Similarly, if cancer induction is simply due to direct hit mutation with no threshold, one would expect a tremendous number of all kinds of tumors in medical personnel and others on parts exposed to radiation; for example, skin cancers on hands. The early radiologists who got such cancers had severe radiation burns with chronic ulcers in which the tumors arose. Some scientists even argue that the cancers arose from the nonirradiated adjacent skin. It deserves emphasis that cancer did not arise on the hands of tens of thousands of people receiving huge quantities in small doses over long periods.

(*c*) Similarly, leukemia development in experimental animals can be prevented by post irradiation infusion of marrow cells indicating that either direct radiation hit is not enough to cause leukemia or that body defense can somehow counteract this damage.

(*d*) The very idea that leukemia and cancers result from a direct hit mutation was never solidly proven and is being challenged recently. Newer evidence unquestionably indicates that some indirect factor plays a determining role in development of leukemias or tumors. Heavy irradiation of some organs can injure specific body regulatory mechanisms and cause cancer indirectly, not by mutation.

(*e*) In case of pituitary or ovarian tumor induction by irradiation, there is no such linear relationship between irradiation dose and response, as is characteristic for mutation. The reverse is true, and there is a clearly defined threshold which is that dose which markedly depresses the function of that organ—about 30 to 50 r. to the mouse's ovary, 30 μc of I-131 to mouse's thyroid.

(*f*) Human cells are eternally submitted to small doses of endless kinds of mutagenic agents; some are endogenous, as hormones; others are extrinsic, as chemicals in food, industry, drugs, et cetera. Even plastics and food dyes can cause cancer in animals under given experimental conditions. These, too, are believed to cause the neoplasm by somatic mutation, but I know not of a single human cancer proven to be caused by them. As to leukemia, many drugs and industrial chemicals injure blood forming organs and could be responsible for increased incidence of leukemia. We have yet to learn to what extent the endless number of potential carcinogens to which man is exposed contribute to development of neoplasia in man, alone and combined.

(*g*) Induction of leukemia in mice from radioactive substances as radiophosphorus and radiostrontium has been reported, as might be expected, from large doses of them, but these reports clearly show existence of a threshold.

RECOMMENDATIONS

(1) Since the medical hazards of radiation are worth taking and since these represent the bulk of radiation hazards, that thus far created by bombology, being a minor evil, should be considered as such. While it is agreed that the latter should be eliminated as expediently as possible with preservation of the safety of the free world, the burden of decision rests not with biomedical investigators, but with miltary experts. All biologists admit the potential hazards of all kinds of radiation and merely argue among themselves about the magnitude of the hazard.

(2) I wish to testify that support for long-term research has been, and still is, niggardly, and it is a disappointing struggle to undertake such research. I recommend liberal long-term support of creative scientists, and incidentally, more centers of knowledge in free institutions. Creative knowledge is our best defense.

Dr. WARREN. I appreciate your allowing me to read this statement of Dr. Furth into the record, Mr. Chairman.

Representative HOLIFIELD. Thank you very much.

Dr. WARREN. Then if I could go back to my own statement.

Representative HOLIFIELD. Certainly he puts the issue very plain in his presentation there.

Dr. WARREN. Yes. He does this on a background of more than 30 years' experience in this field working with leukemia.

Representative COLE. Mr. Chairman, I would like to inquire of Dr. Warren if he could interpret Dr. Furth's comment with respect to the need for long-term research in which Dr. Furth says it is a disappointing struggle to undertake such research. What did he have in mind?

Dr. WARREN. What he has in mind is this: It is much easier to obtain support and much more satisfying for the scientist to work in a field where he can hope to get results in 1, 2, or 3 years, rather than to work with long-term experiments where he may spend his whole life and still come up with an unsatisfactory result at the end of that period of life. This is the sort of thing that makes it so essential to continue on a long-term basis our studies of the population in Hiroshima and Nagasaki. We may get very few results.

I would like to point out that the results at the lower end of the scale that have been used by Dr. Lewis are not considered as actually statistically significant. They may provide a guide, but I would not want to base any firm conclusions on them.

These studies must be continued. But we know that the chances of getting significant results are relatively few. This is a discouraging type of work. It is hard to get support for it because we have to be honest and say it is quite possible that we will spend funds for 20 years and then not have anything to show you. It was that that Dr. Furth was commenting on.

Representative COLE. Thank you.

STATEMENT OF DR. SHIELDS WARREN—Resumed

Dr. WARREN. I would like to make it clear that much has been learned about radiation effects. Now I am speaking for myself. There is much more still to be learned. We have a great deal of data from animal experimentation. We have in addition much data on the effect of radiation on man derived from a number of different sources. These are perhaps worth mentioning.

You have heard of the normal or background radiation to which all of us are subjected. We know that the human race not only has developed in background levels of radiation similar to those of Washington but in regions such as Denver where the radiation is greater. Thus, during 30 years in Washington, a person might receive on the average a total accumulated dose of about 3.1 roentgens. In Denver or other mountain regions, because of increased cosmic radiation, this background might go as high as 5.5 roentgens.

In India a large population has lived for many centuries in the state of Kerala on sandbanks containing monazite. Recent studies of the radiation in this area have shown it to be up to 5 or even 50 times normal background. This population will be studied very carefully medically, but it is of interest that this relatively high level of radiation has not been sufficiently obviously detrimental to the population as a whole to cause abandonment of the region. However, one cannot say what the effects have been until very careful studies have been carried out.

The misfortune of men and women in the past has been wisely utilized by scientists to gain information as to the acute and chronic effects of radiation, and we actually have, as you have heard from the

experts testifying today, a large body of information as to what occurs in man.

To review briefly, we have data on acute exposures at varying levels of radiation from Hiroshima and Nagasaki. The studies on the degree of shielding from radiation afforded by structures in which the survivors were at the time of explosion are now being carried out and will greatly sharpen the information that we now have.

We have data on acute radiation exposure from those involved in the Los Alamos accidents and the minor accident at the Argonne. Some acute radiation from the shorter lived radioactive components of fallout of the close-in type was received by the crew of the Japanese fishing vessel and the Marshallese Islanders in 1954.

Data on chronic radiation in humans derives from the early workers with X-rays and radium as well as from radiologists up to the present day. Also, a considerable body of information has been gathered from patients treated for one or another disease with radioactive isotopes, radium or X-rays.

In general, we know that exposure to acute whole body external radiation will produce death for 50 percent of those receiving about 400 to 600 r.

Second, a single dose of radiation produces life shortening at significant levels. Human beings are too variable in their responses to radiation and in their state of health to permit any direct correlation, but it is probable that an acute dose of about 300 r. or repeated small doses totaling 2 to 3 times that would produce up to 5 years' shortening of life span. It will produce an increased incidence of leukemia. At present the rate of leukemia for the few most heavily exposed survivors at Hiroshima is about 1.3 percent. Radiologists, some of whom have received chronic irradiation on the order of 1,000 r. have 7 to 10 times as much leukemia as has the general population.

If there is a large neutron component in the initial acute exposure to radiation the likelihood of development of cataract is increased.

Radiation, whether acute or chronic, has a definitely damaging hereditary effect, because, in contrast to most cells of our bodies, there is no threshold for damage to the hereditary material and there is no recovery from injury in them. In chronic radiation, this is an important difference between the effects on most cells of a person's body and the effects on his germ cells. Since there is an appreciable power of repair possible in the body cells a higher dose is required to damage them seriously than is required to damage the hereditary material that perpetuates the race.

With acute or chronic radiation there is what is called a threshold effect in body cells. In other words, because many cells can continue to function even though irradiated and many cells in the body can be repaired even though damaged, we find that at low levels of radiation there is no observable effect.

This morning you heard mention of Senator Anderson's wristwatch. My own wristwatch has a luminous dial, and I measured the radiation from this on the back of the watch, putting the measuring device in the position of the skin on the back of my wrist. Assuming that I wore this 12 hours every day—actually I wear it a little more—the skin on the back of my wrist would receive 10 milli-r, or ten-thousandths of an r, and has been receiving it for close to 20 years. Yet this skin is just as normal as is the adjoining skin. That is, I feel

there is a definite threshold effect, and that until this threshold effect is exceeded, I am not going to stop a radioactive wristwatch.

This power of the body to repair itself, other than the hereditary material, has important bearing on the amount of radiation that man can withstand without demonstrable evidence of harm.

The present rate of testing of atomic weapons is such that the radiation from worldwide fallout is appreciably less than the background radiation. From the standpoint of heredity we should watch closely the levels of radiation.

The National Academy of Sciences report on radiation indicates that the doubling dose for mutations probably is in the range of 30 to 80 r, but may be as low as 10 r; it has been suggested that it could possibly go even as low as 5. Many geneticists believe that 30 to 50 r may be the doubling dose.

Representative COLE. Would you explain what you mean by a dou bling dose for mutations?

Dr. WARREN. Yes. There are a certain number of mutations that occur in the race quite naturally at the present time. You have heard of infants that have been born with imperfectly formed digestive tracts, for example. You have seen people who have 1 blue eye and 1 brown eye. These are the extremes of the sorts of mutations, some insignificant and some significant. We have hundreds of thousands of genes, and a change, a mutation in any one of these will produce changes under appropriate circumstances in the cells that are derived wholly or in part from that.

Senator JACKSON. Mr. Chairman—at that point, how can you tell whether it is due to the inevitable process of genetics and how can you tell when it is due to outside influence? How can you trace it?

Dr. WARREN. Only by very careful experimentation. These estimates are based on the best experimental data that we have available at the present time. There is some evidence derived from the eighty-thousand-odd births that have been studied in Hiroshima and Nagasaki as well.

So I would rather not answer that question in detail, because there are others who are geneticists who will be speaking. But in general I feel that we have reasonably sound foundations to emphasize that probably 30 to 80 r is a pretty good estimate for a level of radiation that will bring about twice as many mutations as now occur in the population.

Senator JACKSON. But all mutations are not due to radiation.

Dr. WARREN. No, indeed; not all congenital effects are due to mutations. For example, mutations can be simulated very closely by injury done to a fetus in utero, if the mother has had an attack of German measles or certain of the other types of virus diseases.

Senator JACKSON. While you do not want to go into this, I take it, because this is more a problem for the geneticists, you feel that they can tag and differentiate between mutations that are a natural result—the inevitable mathematical conclusion out of so many births—and mutations due to the outside influence of radiation?

Dr. WARREN. Yes. There is a very large-scale experiment that Dr. Russell, who is carrying on that experiment at Oak Ridge, will go into for you in the course of these hearings.

Senator JACKSON. I think it would be very important because this goes to the heart of the problem and unless you can tag them and

associate them with the problem that we are reviewing here, it would not be meaningful.

Dr. WARREN. Yes. Although not a geneticist, but as a scientist I am firmly convinced that radiation will produce mutations. The estimates that have been made by the majority of geneticists appeal to me as reasonable and sound estimates.

Senator JACKSON. In that connection, Dr. Warren, have there been and studies made of the situation as in Denver where people live at 5,000 feet as distinguished from people living at sea level? I was told that these mutations do not occur as anticipated.

Dr. WARREN. One would have to get a much higher level than occurs in Denver to reach the doubling dose that we have spoken of.

Senator JACKSON. What about in the Andes?

Dr. WARREN. The difficulty in the Andes—I have been at Moracoacha and a number of the other high altitude villages in the Andes—is that the population there is so short lived from other causes—public health is so poor—that it is very difficult to get any satisfactory statistics. I think that we can hope to get much more valuable data from the studies in the monazite areas and these studies are being carried forward by the Indian Government at the present time.

Representative HOLIFIELD. Of course, the length of life in India is much shorter than it is here.

Dr. WARREN. That is quite true.

Representative HOLIFIELD. There are a lot of factors that might enter into it, and not only the comparison of their longevity and ours, but also there would have to be a comparison of the average length of life in India, and those who live on these monazite sands.

Dr. WARREN. Very fortunately there is a very similar population of the same ethnic character and the same social status who live about 10 to 20 miles away. There has been no significant intermarriage between the two groups. So we hope that the Indian Government will have a good built-in control.

I have been speaking of this possible level of the doubling dose of 30 to 50 r. Since there is uncertainty in these figures and since many years of observations will have to be made before they can be firmed up we should take no chances but use a conservative figure such as 10 r for all types of added radiation, of which medical diagnostic X-rays will use a portion.

Representative HOLIFIELD. At this time, in order to get a realization of what a chest X-ray would expose a person to, how many roentgens would you say a person would receive from a chest lung X-ray?

Dr. WARREN. This would depend on the type of X-ray, Mr. Holifield. If it were one of the photoroentgen type, it would be higher than a full chest. We are speaking here not of the direct X-ray, but the scatter from that direct X-ray to the gonads. You heard this morning from a very competent radiologist, Dr. Friedell, and since he is still in the room, I believe, I wonder if he could tell you what he uses. That would make the point even stronger and more real.

Representative HOLIFIELD. Dr. Friedell, I suggest that you come forward. You do not need to leave your chair, sir.

My question, to make it more direct, would be this: What would be the exposure of a chest X-ray—as long as you are here, I will add another—and a fluoroscoping examination of the chest, and what would be the scatter to the gonads?

Dr. FRIEDELL. I am glad you make this distinction. First of all, there is a difference between radiation on the thorax and radiation to the gonads. The radiation to the thorax is considerably larger than to the gonads. As Dr. Warren pointed out, that makes a difference whether you have the miniature kind of chest examination which is really a photograph of a fluoroscopic image or whether you have an ordinary X-ray film that many of you have had for various studies.

Somewhere of the order of six hundredths to one tenth of a roentgen is given to the thorax for an exposure to get a satisfactory chest film. Depending on the various methods that are used for protection of the gonads and the possible protective devices which may be placed over the gonads, the dose to the gonads is considerably reduced. From the scatter alone, it may be as low as one one-hundredth of the dose given to the thorax. I would not want to put a firm figure on it because it is a function of how it is done.

From the point of view of fluoroscopy, there is not any comparison between the amount of radiation delivered to the chest and to the gonads, because of scatter when fluoroscopy is used, because at the present time the fluoroscopic methods require a large dose of radiation to be visible on the fluoroscopic screen. Depending on the time, I would say that a chest could easily receive as much as 5 to 15 roentgens in one examination.

Representative HOLIFIELD. In the case of exploring for a swallowed safety pin by a child, for instance, where you have to probe with instruments, and you follow it with your fluoroscope, what would be the exposure?

Dr. FRIEDELL. That is difficult to estimate, but I think this would help you. Most fluoroscopic machines will turn out somewhere in the order of 5 to 10 roentgens a minute. Some will turn out much more, but they are not really carefully controlled. Generally the lower limit is about 5 roentgens a minute. This determines in effect how much radiation will be received by the body in general, and is generally fairly easy to calculate what might be received by the gonads. If the radiation is directed to the gonads for various reasons, they receive much more.

Representative HOLIFIELD. Do you think there is a comprehension on the part of most radiologists of the importance of the damaging effects of this scatter from a genetics standpoint?

Dr. FRIEDELL. I think this is a difficult question for me to answer. I know that people in whose circle I move are very concerned with the problem and are examining it very carefully. I would say that the radiologists in general are now very acutely aware of this problem. It is conceivable that they were not aware of it 10 or 15 years ago, and are now beginning to institute all the necessary measures to get as much protection as we can.

Representative HOLIFIELD. Certainly when they are utilizing a machine with such potentially damaging effects, they should from a professional standpoint guard the people as much as possible.

Dr. FRIEDELL. I think I would agree with this, but I would also like to add to this that you are always faced with the problem of measuring the value of this medically as compared with the possible hazard that is introduced. This is a very difficult thing to measure sometimes. It is conceivable that much error can be introduced, but

I think that most physicians are acutely aware of weighing these two things and must do the best for the patient.

Senator HICKENLOOPER. I would like to ask Dr. Friedell or Dr. Warren a question or two.

I wonder if you ever knew Dr. Erskine?

Dr. FRIEDELL. Yes, in Iowa.

Senator HICKENLOOPER. He was an old friend of mine who died a few years ago. He died without doubt from radiation which he got in the early days from his experimental work. He did some pioneering work, especially on the mechanics of measurement of radiation in those days.

The question I want to ask is somewhat along the line of Congressman Holifield's question. From a statistical standpoint, I think manifestly years ago—20, 30, 40 years ago—when the average small or large town physician's office did not seem complete unless he bought an X-ray machine, and without doubt used it with great frequency without realizing the potentials of this machine, without the ability to measure quantities or absorption or anything of that kind, and with little or no schooling in it, I wonder if there is any statistical background that would tell us how many cases of leukemia or perhaps induced cancer or something of that kind might have occurred in the American population during those periods when there was very little appreciated as to the long range possible effects of radiation of this kind.

Dr. WARREN. I think I might be able to answer, if I might, Senator Hickenlooper.

Senator HICKENLOOPER. Yes.

Dr. WARREN. I had been interested in the problem of the life span of both radiologists, general practitioners and certain specialists. We find that the life span of the general practitioner is not significantly at variance with the life span of white males over 25 in the United States. The average doctor starts his practice somewhat around 25 years of age, so that is what we took.

This means, then, that the average doctor, not a specialist in radiation or not in the specialties using radiation a great deal, such as orthopedic surgery, urology and some of the other specialties, has about the same life span. There is evidence that he has slightly more leukemia, but not as much as the radiologist who has 7 to 10 times as much as the males in the general population. He has possibly half again as much. It is rather hard to pin it down exactly.

I think it should be remembered that there are relatively few of the general practitioners who used their X-ray machines all day long. They would use them from time to time on their patients, and had appreciable rest periods during which their body cells could recover from the radiation injury done.

Senator HICKENLOOPER. I either heard or read some testimony with respect to the data on physicians, but the real point of my question I was directing at the use of X-ray in treatment years ago on patients when the effects of those X-rays were not so well known, and there was a period of time some years ago when it was really quite widespread, and there is no telling what the strength of the treatment would be that many patients received at that time. I wonder if there would be any statistical data that could indicate malignancies of various types from that treatment, rather than from natural causes.

Dr. WARREN. You saw on the chart an estimate as to X-rayed adults here. I think that the best data on this are the group with so-called ankylosis spondylitis—a form of arthritis of the spine—an X-ray treatment gives some relief to the pain and may help the course of the disease somewhat. A group under the direction of Dr. Court Brown in England studied this very carefully. I have here the white paper on radiation effects issued by the United Kingdom approximately a year ago. It gives an indication that the dose ranges ran from as little as 500 *r*, or possibly a little under that to the spine, up to more than 2,750 *r*; that this caused an increase in the crude incidence of leukemia—these are uncorrected figures—ranging from 4.1 per 10,000 people treated at the lower dose level, or 2.2—which might be sheer chance, at less than 500 *r*—up to 17.6. So arguing from this, I think it might be said that there were probably a scattering of cases of leukemia induced in the way you spoke of.

Senator HICKENLOOPER. Would you have an estimate at this time as to how long a period of time it has been since you feel that you can have some reliable data on leukemia, and many other ailments which people undoubtedly had many years ago, but which were not diagnosed by the physicians? I remember when they used to say people died of acute inflammation of the bowels, when it was probably a burst appendix, and that sort of thing.

Dr. WARREN. Yes. I think you pointed out a very important thing, Senator Hickenlooper, that medical diagnosis is steadily improving. I think in certain areas of the country in the larger medical centers, leukemia has been pretty well recognized from 1930 on; for the bulk of the country, leukemia has been very well recognized from 1945 on. I think our statistics from 1900 to 1910 may have caught perhaps half of the leukemia cases or something of that order. This is only a wild estimate, however.

Senator HICKENLOOPER. Thank you very much.

Representative HOLIFIELD. Thank you very much. You may proceed with your statement.

Dr. WARREN. At present the rate of radiation from fallout gives a probable 30-year dose of 0.1 roentgen. The data on chronic radiation to our bodies and those of animals indicates that rather more than the acute lethal dose of radiation can be withstood, though not without harm, if it is given over a protracted period of time. The effect of protracted radiation may be half or less as great as radiation given at a single time. If significant damage is done to body cells there is never complete repair, but rather atrophy persists and eventually cancer may develop.

The ill effects known to come from chronic radiation, are, as you have heard, damage to various body tissues ranging from the destruction of cells to undue or cancerous proliferation of cells. Thus, in the skin of the early radiologists, we saw atrophy occur, finally ulceration, and in some instances even skin cancer. The blood responds at first to radiation at low levels by minute and insignificant changes in some cells. For example, the lymphocytes may show a rare cell with double nuclei, the meaning of which has not yet been established. Continued exposure to radiation leads in some people to the failure of formation of adequate blood cells condition known as anemia or agranulocytosis, or, at times, to an overly enthusiastic reparative response which leads to the development of leukemia. Chronic exposure

from radium, particularly radium absorbed internally, has been shown to be injurious and radiation changes in bone can be detected with levels of radium in bone as determined years afterwards on the order of 1 microgram. Of course, these levels were initially appreciably higher.

Since one of the radioactive fission products, strontium 90, is deposited in bone, there is much concern to advance our knowledge of radioactive strontium, the amount that enters our bones, and the effect that it may have there. Strontium 90, at fallout levels or at levels many times higher, has no significant genetic effect. Neither is there firm evidence that it has a leukemia producing effect. If we assume that the radiation effect from strontium 90 or from other sources has no threshold (and this assumption is contrary to most existing information with regard to somatic effect) if we assume this, I say, it would follow that there would be a small statistical increase in bone tumors. I doubt very much that it would cause any increase in leukemia. It is striking that in those persons who have had radium deposited in their bones there has been no evidence of leukemia, even though they have developed bone sarcoma. The evidence for the possible development of leukemia from strontium 90 rests on mice treated with radioactive strontium that showed leukemia. However, leukemia is so common a disease spontaneously in mice that I hesitate to accept this observation as contradicting the information we have from experience with humans and with a number of animal experiments at the present time.

Let us, however, make the worst assumption, that there is no threshold and that we might be concerned with a linear increase in both leukemia and bone sarcoma. On this basis, as you have heard, the average level to be expected from uptake of strontium 90 already produced by weapons testing may be about five so-called sunshine units. While there is no evidence that even 10 times this level is harmful, if we assume that there is no threshold, I would be reluctant to see the average strontium 90 content of bones, particularly in children, go much above 10 times the present level. It is possible that additional experimental work will enable us to go safely beyond this tenfold increase.

Representative HOLIFIELD. Thank you very much, Dr. Warren.

Senator Jackson, do you have any questions?

Senator JACKSON. I have no further questions. I am very happy to see Dr. Warren back with us. We are very proud of his great contribution while he served as Director of the Division of Biology and Medicine of the Atomic Energy Commission.

Dr. WARREN. Thank you very much, Senator Jackson.

Representative HOLIFIELD. Dr. Warren, will you be back with us in a few minutes for our discussion period?

Dr. WARREN. Thank you.

Representative HOLIFIELD. At this point I would like to say that it is my understanding that Dr. L. H. Hempelmann, of the University of Rochester, Strong Memorial Hospital, will deliver a paper in Pittsburgh on June 11, called Irradiation-Induced Cancer in Man. When we receive a copy of this paper I would like to insert it into the record at this point.

(The material referred to follows:)

IRRADIATION-INDUCED CANCER IN MAN

L. H. Hempelmann

The possible development of cancer, and this includes leukemia, is an occupational hazard known to persons working with X-rays or nuclear radiation. Recently, this type of radiation carcinogenesis has become a matter of increasing concern to the scientific world and to the world at large. There are several reasons for this. The first is the exposure of ever increasing numbers of people to man-made radiation. (This includes not only persons working in the field of atomic energy, but also people receiving the benefits of Western-style medicine, and indeed the entire world population now that the radioactive fallout from the hydrogen bomb test programs is worldwide.) The second reason for concern is in the observation that the radiation doses necessary to induce cancer are smaller than they were believed to be formerly. The third reason for the current interest in radiation carcinogenesis is the recent evidence which challenges the concept that all somatic effects of radiation are threshold reactions.

For more than 50 years, it has been known that X-rays and gamma rays can cause cancer. The first case of skin cancer in an X-ray worker was reported in 1902. Gamma rays were the first carcinogenic agent used in the laboratory to produce experimental cancer in animals. In the past half century, the literature concerned with radiation-induced cancers has become voluminous. Review of the literature shows that almost any tissue of the body will undergo malignant change under proper conditions of exposure. In most instances, these exposure conditions involve repeated or chonic irradiation of a small volume of tissue with doses totaling several thousand roentgens. This is not the kind of radiation-carcinogenesis I will consider today. Instead I will confine my attention to the incidence of malignant disease in four human populations in which the total body of each individual, or at least a substantial portion of the body, was exposed to ionizing radiation. I will also mention a retrospective study in which the history of previous radiation exposure has been determined for a group of children with leukemia and other forms of cancer.

The first group of exposed individuals in whom the incidence of malignancy has been studied is composed of the radiologists. Since the first recorded case of leukemia in a radiologist in 1912, it has been suspected that there might be an association between this disease and prior radiation exposure. This suspicion was supported by experiments in animals which showed that leukemia could be produced by irradiation with X-rays. In 1942, Henshaw and Hawkins made a systematic study of the causes of death in physicians. They observed that the incidence of leukemia in physicians was slightly higher than it was in the general male population. Several surveys have been carried out since this time to determine the incidence of leukemia in radiologists. Probably the best figure illustrating the increased leukemia rate is that of E. B. Lewis who has calculated the age-specific death rate from leukemia for radiologists and for the adult male population. He estimates that the death rate from leukemia in radiologists is approximately eight times the expected rate for the general male population. While this figure of eight-times-normal is strikingly high, it is important to emphasize the fact that leukemia is a rare disease and that the actual number of people who contract it, even among the radiologists, is not great. Up to 1948, only 37 cases of leukemia were reported in the medical literature among the thousands of people who had worked with X-rays during the preceding 50 years. I should also like to mention the fact that the cases of leukemia usually occurred late in the life of the radiologist. The average age of death of all radiologists dying from leukemia was almost 59 years. This is essentially the same as the 60-year average age at death from all causes. I should like to emphasize the fact that aside from leukemia and skin cancers, the incidence of other forms of interval cancer in radiologists is not increased. Incidentally, I should like to point out that the exposure of the radiologists is partial body rather than total body and is protracted over a period of many years.

The second group showing an association between leukemia and radiation exposure is the Japanese people exposed to the radiations from the nuclear detona-

tions in 1945. Table 1 shows how the incidence of leukemia can be correlated with the distance of the exposed individuals from the hypocenter under the explosion. In the last column, you can see the ratio between the observed and expected incidence of leukemia. With regard to the interpretation of these data, I would like to point out that the irradiation of these individuals, unlike that of the radiologists, usually involved exposure of the entire body to a single dose of mixed irradiation, primarily consisting of gamma rays. Dosage data are uncertain but the dose certainly falls off with increasing distance from the hypocenter. The latest unclassified figures that I have seen indicate that the mean dose for each of the exposure zones is 1,500 rem for the first zone, 500 for the second and 50 for the third. These are not firm figures and do not take shielding among other factors into account. To show how uncertain they are, I would like to point out that almost all the cases of leukemia occurring in persons in the 1,500 to 1,999 meter zone had severe radiation complaints; it is difficult for me to believe that they did not receive considerably more than 50 rem.

TABLE 1.—*W. M. Court Brown, R. Doll, Hazards of Nuclear and Allied Radiations (table 2A, p. 85): A comparison between the observed and the expected incidence of leukemia among survivors of the Hiroshima atomic bomb explosion exposed at various distances from the hypocenter; persons subsequently resident in Hiroshima City only*

Distance from hypocenter at time of explosion (m.)	Number of cases with onset in the 8-year period 1947-54		Number of deaths expected among the survivors in an 8-year period [1]	Ratio of total cases observed to expected
	Confirmed	Suspected		
Less than 1,000	15	0	0.15	100.0 : 1
1,000 to 1,499	28	1	1.32	22.0 : 1
1,500 to 1,999	6	1	2.33	2.6 : 1
2,000 to 2,999	6	0	3.96	1.5 : 1
3,000 or more	4	2	4.83	1.2 : 1
All distances	[2] 59	4	12.59	4.7 : 1

[1] Calculated from the Japanese mortality data for 1952. In calculating the numbers of expected deaths, certain assumptions had to be made about the rate of change of the numbers of survivors in the different age groups, and the figures must be regarded as approximate estimates.

[2] Two cases referred to in table 1A are omitted, since the onset of symptoms in one patient was in 1955 and in another patient, who died in April 1955, the date of onset is unknown; the latter patient was exposed at a distance of 2,400 meters from the hypocenter.

The third exposed population is a series of patients with a severe form of rheumatic disease of the spine known as ankylosing spondylitis. This is a painful, crippling disease occurring mainly in young men. Intensive X-ray therapy has often been used with considerable success in treating this illness. X-ray doses of 2,000 r. given to the entire spinal column through ports 10 cms. wide are not unusual. Such treatments are not given all at once but are usually fractionated over a period of weeks. Such a series of treatments is often repeated once and possibly twice. In a group of 15,000 patients in Great Britain, the incidence of leukemia has been determined. Table 2 shows how the 37 cases found in this group were distributed according to the total dose administered to the bone marrow. These data show a linear relationship between leukemia rate and dosage. If we extrapolate to the lower dose range, it is observed that the dose of radiation to the spine necessary to double the incidence of leukemia is of the order of 100 roentgens. If the dosage data is expressed not in terms of roentgens to the bone marrow but, rather, in terms of megagram-roentgens to the body, the relationship between dose and incidence is curvilinear rather than linear. One criticism usually directed at this type of clinical studies on X-ray therapy patients is the lack of a really good control group with which to compare the treated patients. The British were able to collect as controls only 400 patients with spondylitis not treated by X-rays. Another criticism that I would like to point out is the small number of cases in the low-dose range, only 2 cases of leukemia having occurred in patients receiving less than 500 r. to the spine.

TABLE 2.—*W. M. Court Brown, R. Doll, Hazards of Nuclear and Allied Radiations (table 2B, p. 89): The numbers of male patients developing leukemia and the crude incidence rates after different doses of radiation (measured by the maximum amount received at a point in the spinal marrow)*

	Amount of treatment, maximum dose to the spinal marrow (r.)						
	0	Less than 500	500 to 999	1,000 to 1,499	1,500 to 1,999	2,000 to 2,749	2,750 or more
Number of men developing leukemia	----------	2	8	8	8	6	5
Crude incidence per 10,000 men per year	[1] 0·5	2·2	4·1	4·2	11·3	13·0	17·4

[1] The rate given for "no treatment" has been estimated from the national vital statistics for all forms of leukemia, and weighted to allow for the fact that not all the patients in the series were certified as dying from leukemia. If lymphatic leukemia is excluded (as may be more appropriate) the rate is 0·3.

The fourth population I would like to discuss consists of 1,700 children treated with X-rays in infancy. They were treated for a condition known as enlargement of the thymus gland which in the past has been alleged to be associated with sudden death of a previously healthy child or with severe and sometimes fatal respiratory distress in young children. When a diagnosis of thymic enlargement was made in a sick child, it was customary to treat the child with a beam of X-rays to the region of the chest. In the 1920's and 1930's, doses of 500 or 600 roentgens or more have frequently been administered through ports which covered the entire chest of the child. Fear of the consequences of thymic enlargement became so intense that asymptomatic children who were suspected of having this condition were often given prophylactic X-ray treatment to prevent symptoms. In one city in upstate New York it has been found that approximately 1 percent of the children born between 1925 and 1950 have been treated with X-rays for thymic enlargement. This form of treatment is still used at the present time but the practice is less common and the port size is considerably smaller now.

Table 3 shows a comparison of the observed and expected incidence of cancer in children given X-ray treatment for thymic enlargement. You can see that whereas 2.6 cases of cancer would be expected to occur in a normal group of children of this size and age distribution, 17 or probably 19 were found ; 0.6 of a case of leukemia should have occurred but instead 7 or probably 8 have been found. The most striking increase of all is found in the case of thyroid cancer where 0.09 case was expected and 6, or more recently 10, cases have been observed. Now as controls we have 2,000 untreated siblings of the children which, I admit, are not good controls. Nevertheless, they have 5 cases of cancer rather than the 2.7 expected cases and no cases of leukemia or thyroid cancer. (It does seem clear that this group of children with thymic enlargement treated with X-rays has an increased incidence of cancer.) Table 4 illustrates how these cases of malignant disease were distributed among the children who received more or less than 200 roentgens. In the case of leukemia, you can see that there were 2 cases among the 600 children receiving less than 200 roentgens and 5 cases among the 800 receiving more than 200 r. Although the number of cases is small, it seems likely that there is a relationship between the size of the dose and leukemia incidence. No other cases of cancer, however, were observed in children receiving less than 200 r.

TABLE 3.—*Expected and observed rates for malignant neoplasia* [1]

	Treated children		Untreated siblings	
	Expected	Observed	Expected	Observed
All cancers	2.6	17 (?19)	2.7	5
Leukemia	.6	7 (?8)	.6	0
Thyroid cancer	.08	6	.08	0

[1] From study by Simpson, Hempelmann, and Fuller on 1,722 children treated with X-rays for thymic enlargement from 1926 to 1951.

TABLE 4.—*Distribution of neoplasia according to amount of radiation*[1]

	Under 200 r.	Over 200 r.	Unknown
Number treated	604	804	313
Cases of leukemia	2	5	(?1)
Other cancers	0	4	0
Carcinoma of thyroid	0	6	0
Adenoma of thyroid	0	6	3

[1] From study by Simpson, Hempelmann, and Fuller on 1,722 children treated with X-rays for thymic enlargement from 1926 to 1951.

The last study that I would like to mention is a so-called retrospective study of the history of previous X-ray exposure of 547 British children who died before the age of 10 from leukemia and other forms of cancer. The controls in this study consisted of the best friend of the child at the time of his death. Information was obtained from the parents as to exposure of the mother as well as the child and table 5 shows the information so obtained. I will mention the only category in which a significant difference was found in the history of X-ray exposure of the two groups of children. This category involved X-ray examination of the abdomen of the child's mother during pregnancy and this is seen in the first row of figures. You can see that whereas only 24 mothers of the control children had this form of examination, 42 or almost twice as many mothers with children with leukemia were examined in this way. This is 42 out of 269. A comparable difference also hold the exposure of the mothers of children with other forms of cancer and of the control children. There were 21 such examinations in the controls and 43 in the mothers of children with cancer. Now if you assume a cause-and-effect relationship here, you can see that all cases of childhood leukemia in this series cannot be explained on the basis of X-ray exposure of the fetus. Only about 8 percent of the total cases had this type of X-ray exposure. I would like to point out here that the doses involved in this type of X-ray examination are small. The fetus received about 2 roentgens per X-ray film and usually 4 to 6 films were taken per examination.

TABLE 5.—*Lancet, Sept. 1, 1956: Past histories*[1] *of X-ray examinations and antibiotics in 547 children with malignant disease and 547 controls matched for age, sex, and locality*

Number of mothers and children X-rayed		Leukemia		Other malignant diseases		All malignant diseases	
Period	Type of exposure	269 cases	269 controls	278 cases	278 controls	547 cases	547 controls
Antenatal	Diagnostic:						
	Abdomen	42	24	43	21	85	45
	Other	25	23	33	32	58	55
Before conception of survey child	Therapeutic	------	------	------	1	------	1
	Diagnostic:						
	Abdomen	17	24	28	30	45	54
	Other	103	88	108	119	211	207
Postnatal (children only)	Therapeutic	1	------	1	------	2	------
	Diagnostic	45	49	46	50	91	99
	Shoe fittings	55	52	40	46	95	98
Total number of mothers[2]		140	130	160	154	300	284
Total number of children		89	91	75	84	164	175
Either mother or child, X-rayed		179	172	194	198	373	370
Postnatal medication (children):							
Sulfonamides		51	45	42	42	93	87
Antibiotics		68	52	50	58	118	110

[1] I. e., before the onset of the fatal illness in the affected child or equivalent period in the control child.
[2] Since a mother or child may appear in more than 1 X-ray category, the totals in this category are less than the sum of totals in the 3 preceding ones.

In summary, I would like to show (table 6) a recent paper published in Science by E. B. Lewis, on the relationship between leukemia and radiation exposure. He has taken the data from the first four surveys that I discussed and has calculated the probability of any single individual developing leukemia per rad absorbed in the bone marrow. The figures in the last column give his best estimate of probability turn out to be $1-2\times10^{-6}$ per year. It could be chance, of course, that these calculations turn out to be so close, and it must be admitted that the dosage data in the first two groups are not accurately known. If it is not coincidence that these probabilities are practically identical, then the data suggest that the amount of blood-forming tissue exposed and the time during which the exposure takes place are not matters of great importance in the induction of leukemia. In this respect, then, the leukemogenic effect of radiation would seem to be cumulative.

In conclusion, I would like to say that the data obtained from surveys of exposed human populations indicate that there is a clear association between leukemia and previous radiation exposure. The incidence of cancer, particularly thyroid cancer, may be increased in children irradiated before or after birth. But there is no evidence that other forms of cancer are more frequent in adult populations exposed to total body radiation. In the case of leukemia there seems to be a definite relationship between the incidence of the disease and the dose of radiation provided the exposures are high. The data at hand is insufficient to allow us to conclude that this relationship also holds for low-dose levels. I would like to emphasize the fact that the risk of any given individual developing leukemia is small even if he has received considerable exposure, but when large populations are involved the absolute number of people affected may be large.

TABLE 6.—*E. B. Lewis, Science: Summary of the estimates of the probability of radiation-induced leukemia per individual per rad per year*

Source of estimate	Type of radiation	Region irradiated	Types of leukemia produced	Probability of leukemia of specified type per individual per rad (or rem) to region irradiated per year		
				Estimated range		Best estimate
				Lower limit	Upper limit	
Atom-bomb survivors	Gamma rays plus neutrons	Whole body	All	0.7×10^{-6}	3×10^{-6}	2×10^{-6}
Ankylosing spondylitis patients	X-rays	Spine	Granulocytic (only?)	0.6×10^{-6}	2×10^{-6}	1×10^{-6}
Thymic enlargement patients	do	Chest	Lymphocytic (only?)	0.4×10^{-6}	6×10^{-6}	1×10^{-6}
Radiologists	X-rays, radium, etc	Partial to whole body	All (?)	0.4×10^{-6}	11×10^{-6}	2×10^{-6}
Spontaneous incidence of leukemia (Brooklyn, N. Y.).	All natural background sources	Whole body	do		10×10^{-6}	2×10^{-6}

tion is increased, but there is no mutation that is characteristic of radiation. There are a great variety of mutations that are brought about. I think this goes back to the very sound point made by Dr. Pollard and some of the earlier speakers, that the significant changes are changes that take place in the fundamental building blocks of our cells, and the manifestation of these changes may be apparent in quite a wide number of ways.

Representative HOLIFIELD. Dr. Jones, do you have something to add?

Dr. JONES. When I have my next turn, I will have something to say.

Representative HOLIFIELD. Dr. Friedell, do you have a comment?

Dr. FRIEDELL. I have no prepared comments. I think I would have to state my position as saying that I am concerned by what these gentlemen have said, but not yet fully convinced.

First of all, I think you want to make sure that the selection of cases from both groups are exactly the same. Apparently evidence is being presented which shows these may be comparable. I think it is important to show that the activity of radiology itself does not attract into it people who are likely to have a higher death rate, especially at the higher ages, because very early in radiology an individual who had one sort of illness or another was often given the advice to enter radiology, because it appeared to be a sedentary occupation. I do not know whether this in any way alters the figures at all, but I think it is well to look at this from every point of view. It is difficult trying to make this decision from the statistics alone.

An example of how this might occur is something that was presented by George Bernard Shaw many years ago. He was violently opposed to immunization as I think many of you know. Statistics were presented to him to show that as immunization increased, various communicable diseases decreased in England. He hired somebody to count up the telegraph poles erected in various years in some particular streets, and it turned out that telegraph poles were being increased in number. He said, "Therefore, this is clear evidence that the way to eliminate communicable diseases is to build a lot of telegraph poles."

All I would like to say here is that the important point is that if you really want to understand it, you have to look at the mechanism of the occurrence. I think this is where the emphasis should lie.

I am very pleased to have Dr. Pollard speak to this matter as he did this afternoon.

Representative HOLIFIELD. I will withhold my remarks until I ask Dr. Brues to comment, and then back to Dr. Jones.

Dr. BRUES. I think a lot of specific comments have been made. I would like to make a sort of general one about scientific evidence, because that seems to come up here.

If you have two experiments with the same kind of mice treated in the same way, you will expect the second one to come out the same way the first one did. You take a prediction of that sort as simply representing honesty on the part of the investigator. That is why the experiment was repeated in which the irradiated mice lived a little longer because it was difficult to believe, and needed to be confirmed. I think perhaps a lot of our experiments that came out the "right" way should be repeated also.